VOL. XII JANUARY 1958 NO. 1

PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

IN THIS ISSUE: Fosberg and Corwin — *Fossil Flora from Pagan* • Fosberg — *Vascular Flora of Pagan Island* • Roden — *Oceanographic and Meteorological Aspects of the Gulf of California* • Bary, de Stefano, Forsyth, and van den Kerkhof—*A Closing, High-speed Plankton Catcher for Use in Vertical and Horizontal Towing* • Wisner — *Is the Spear of Istiophorid Fishes Used in Feeding?* • Pettersson and Frederiksson — *Magnetic Spherules in Deep-sea Deposits* • Paramonov — *Lord Howe Island, a Riddle of the Pacific; Review of Australian Species of* Laphria *(Asilidae, Diptera), with Descriptions of Three New Species from Lord Howe Island* • Wieser — Protohydra leuckarti *in Puget Sound*

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(Continued on inside back cover)

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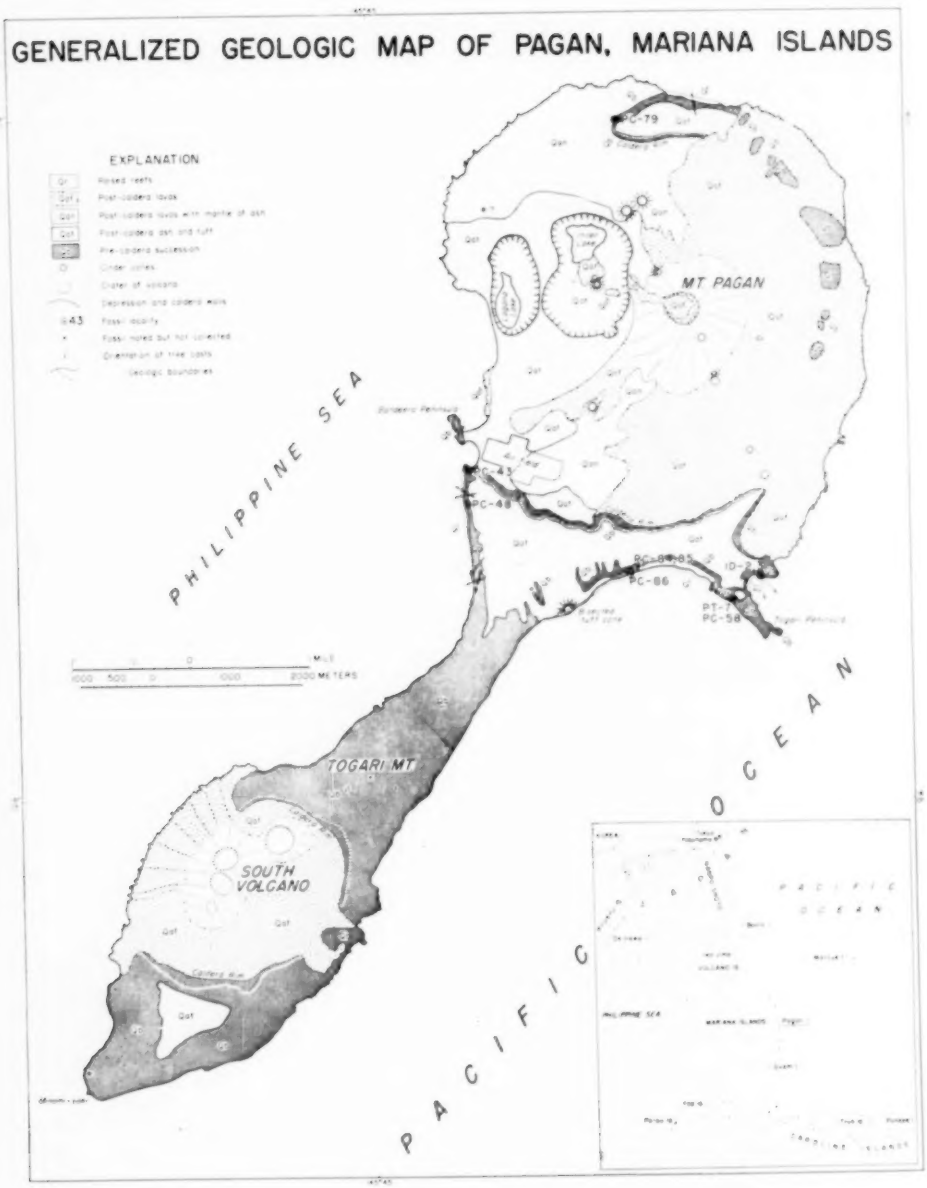

FIG. 1. Generalized geologic map of Pagan, Mariana Islands.

A Fossil Flora from Pagan, Mariana Islands[1]

F. R. Fosberg[2] and Gilbert Corwin[3]

Pyroclastic deposits on Pagan, northern Mariana Islands, contain numerous plant impressions. During geologic investigations in 1954, ten collections were made for subsequent identification and study. Seventeen plant species, all of which now live in the Marianas, have been distinguished.

The geologic investigations of Pagan were undertaken by a field party of the Office of the Engineer, U. S. Army Forces, Far East, staffed by members of the U. S. Geological Survey. L. D. Bonham of the field party first noted the plant fossils. Gilbert Corwin, with the aid of M. J. Terman, also of the field party, and Santiago V. Castro, a resident on the island, collected samples and made field studies of the fossil localities. Fosberg has identified, studied, and described the plant impressions.

Location and Geography

Pagan Island is near the center and is the largest of the northern Mariana group. It lies between latitudes 18°01′ and 18°11′ North and between longitudes 145°41′ and 145°49′ East, about 280 miles north of Guam and 1,100 miles south-southeast of Tokyo, Japan (Fig. 1).

The northern Mariana Islands form a chain nearly 300 miles long that consists of the summits of large volcanoes rising from ocean depths of as much as 6,000 feet. Uracas (Farallon de Pajaros) at the north end is one of the most active volcanoes of the western Pacific. Pagan, Asuncion, Agrigan, and Guguan have had eruptions since 1900 (Tanakadate, 1940). The islands are generally small, relatively high, and rugged. The maximum elevation of 3,136 feet is at the summit of Agrigan Volcano.

Pagan consists of two active volcanic centers located within broad circular depressions (calderas) that are connected by a high rugged isthmus. It has an area of 18.4 square miles and a greatest elevation of 1,890 feet near the south end of the isthmus.

The northern caldera is 3½ miles in diameter and has one large central cone, Mt. Pagan, that has an elevation of 1,855 feet. Relatively recent basalt flows are extensive and form broad plains north, east, and south of the volcano; ash is concentrated to the west (leeward).

The southern caldera is about 1½ miles across. South Volcano within it consists of four coalescing cones, three of which have broad steep-sided craters. Rough lava plains bound the volcano on the north, east, and south. To the west the volcano slopes directly to the ocean.

The isthmus ranges in width from about ½ mile at the north end to 1 mile at the south end. Northward along the crest of the isthmus, the peaks become successively lower. The caldera backslopes north of the isthmus are dissected by numerous valleys directed away from the rim of the northern caldera.

The volcanic rocks have been divided into two major groups: pre-caldera and post-caldera. Both consist of flows and pyroclastic rocks.

The older, pre-caldera group is well exposed in the caldera walls, along the coasts of the isthmus and southern end of the island, and in old sea cliff remnants north and northeast of Mt. Pagan (Fig. 1). The lavas and pyroclastic rocks are products of eruptions by at least four major volcanoes and a number of minor vents aligned along or near the axis of

[1] Publication authorized by the Director, U. S. Geological Survey. Manuscript received March 4, 1957.

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the island. The largest of the old volcanoes was probably in the position of the present Mt. Pagan. The uppermost unit of the succession is composed of a widespread thick tuff-breccia sequence.

The pre-caldera group is probably of late Quaternary age. Sea cliffs have been cut in the breccias and older deposits; and reef limestones, some of which are now as much as 5 feet above present sea level, have since been deposited on the wave-cut platforms. Similar sea cliffs flanked by terraces and raised reef limestones have been noted on the coasts of many Pacific islands and are attributed to erosion and deposition during post-glacial high stands of sea level. Sea levels 5 to 12 feet higher than the present one have been assigned various dates ranging from about 1,000 to 5,000 years ago. Some plants that may have been introduced by man are represented by impressions in samples collected from the upper breccias and therefore may indicate a maximum age for these breccias of about 4,000 years—the probable length of time since the advent of man in Micronesia (Spoehr, 1955*a*, 1955*b*).

The post-caldera succession is concentrated within the calderas. At some places lavas have flowed over the caldera rims; tuff as much as 30 feet thick mantles large portions of the caldera blackslopes and the isthmus.

Historic records of eruptions are scattered, conflicting, and incomplete. It is likely that several major eruptions have taken place within the past 200 to 300 years. Marche (1891: 261) states that a major eruption occurred in 1872. Extensive lavas northeast and southwest of Mt. Pagan and a thick tuff sequence to the west were probably deposited at this time. Eruptions since 1900 have been minor.

VEGETATION

The present-day vegetation of Pagan gives a general impression of semi-aridity. This is probably not so much a reflection of climatic dryness as of an extremely porous substratum and of the pioneer nature of vegetation, which occupies surfaces of recent volcanic ejecta. In the very few low, wet areas, such as to the west and southwest of the Inner Lake, thickets of broad-leafed trees are luxuriant enough, and places bordering the lake are somewhat marshy. Luxuriant patches of woods also exist in hanging valleys on the west side of the south end of the island. A mixed scrub forest of low stature forms thickets and patches up to several acres in extent on plains north and south of Mt. Pagan — extending up its lower slopes in places on steep slopes on the west shore of the isthmus, and in numerous ravines throughout the island. There has been no investigation of the actual composition of this forest, but it contains 15 or more species of trees.

The loose volcanic ash that covers large areas, especially on the west side, is largely vegetated by an almost pure stand of swordgrass, *Miscanthus floridulus* (Labill.) Warb. This forms a coarse, harsh, brake-like grassland 1 to 3 m. tall and very dense in places. On the steepest slopes and above 250 m. altitude this grass tends to be shorter and the clumps more widely spaced. Above 450 m. it is sparse to absent.

Lava flows may be practically bare, as on the northeast side of Mt. Pagan; they may support scattered clumps of *Miscanthus* and trees of *Casuarina*, as on the east and southeast sides of Mt. Pagan and the central upland of the southern part of the island; or, as on many of the flows and lava cliffs to be seen along both sides of the island, they may be covered by almost pure forests of *Casuarina*. *Casuarina* and the fern, *Nephrolepis hirsutula* (Forst. f.) Presl, are among the earliest invaders on new lava. Both species were well established on a fresh black *aa* flow in the depression at the west base of Mt. Pagan in 1950. This flow has been dated by Tanakadate (1940) as having occurred in 1925. It shows no visible weathering.

On plains of ash soil the vegetation is gen-

erally grassland with scattered trees or clumps of trees. The trees may be *Pandanus*, *Casuarina*, or any of a number of broad-leafed species. Many of these areas were under cultivation before World War II and are weedy and have rows of *Casuarina* and other trees planted by the Japanese as windbreaks. *Jatropha gossypifolia* L., a fleshy-stemmed shrub introduced by the Japanese in the 1930's, has spread and now dominates large areas in the central part of the island. Clumps of trees of various kinds mark the sites of houses, still existing or not. On the gently sloping northwest part of the island is a large coconut plantation. There are smaller ones in many parts of the island, both on plains and on talus cones. Coconuts are also common in ravine mouths and on steep slopes above the sea. The large plantations are of relatively recent date, but there is no way of knowing the age of smaller clumps of coconuts that are mixed with other vegetation on various parts of the island. Some may very well date from before European visits to the island.

FOSSIL LOCALITIES

All samples of plant impressions are from the northern half of the island, mostly from tuff of the pre-caldera succession. Impressions were noted in talus blocks at the foot of a high cliff at the south end of the island but no specimens were obtained. One sample (PC-86) was collected from post-caldera tuffs forming the surface of a terrace northeast of the bisected tuff cone; other impressions in post-caldera deposits were observed on the uplands east of the cone.

Samples from the pre-caldera succession represent several stratigraphic horizons (Table 1). Most collections are from tuffs that underlie or are included in an extensive tuff-breccia sequence near the top of the succession. One of the most accessible localities (PC-43) is at a sharp bend in the trail at the west end of the caldera rim. Three samples (PC-58, PC-79, PT-7) are from tuffs associated with lavas or volcanic breccias that underlie the upper breccias.

Impressions of tree trunks were observed near the base of the upper breccias at several places (Fig. 2). In all cases the impressions are nearly horizontal and therefore represent fallen branches and trunks. Many are oriented about parallel to radii from Mt. Pagan, suggesting that a powerful explosion from the mountain felled the trees.

THE FOSSIL PLANTS

Almost the entire collection consists of leaf impressions, most of them fragmentary. Some of these have no features preserved that would make possible even tentative determinations. Very careful scrutiny shows that in the entire

FIG. 2. Tuff overlying lava and underlying tuff-breccia at the west end of the caldera rim. Plant impressions were collected from the tuff below and interbedded with the dark colored cindery layers in the upper part of the picture. The hole in the cindery layer was probably formed by decay of a tree trunk that had been buried by the ash. The sides of similar holes elsewhere commonly retain impressions of tree bark. A deformed tuff layer near the center of the picture may represent the soil horizon in which the plants grew.

TABLE 1
AGE SEQUENCE OF SAMPLES CONTAINING PLANT FOSSILS, COLLECTED ON PAGAN ISLAND

NUMBER	AGE AND LOCALITY*	LITHOLOGY	STRATIGRAPHIC RELATION
PT-7	Pre-caldera; Togari Peninsula.	Well-indurated, reddish, fine-grained, laminated tuff.	Tuff associated with breccia underlying thick flow and cinders of a minor vent; underlain by thick succession of lavas and pyroclastic rocks derived from old volcano to southeast.
PC-58	Pre-caldera; Togari Peninsula.	Same.	
PC-79	Pre-caldera; north end of island.	Poorly consolidated brownish tuff containing numerous pellets. Some fine-grained yellow to reddish soil layers associated.	Tuff overlain by pre-caldera lavas which are overlain in turn by the upper breccias. Underlying tuff breccias mostly covered by talus.
PC-43	Pre-caldera—base of upper breccia sequence; west coast, west end of caldera rim.	Poorly consolidated brownish to gray tuff and cindery tuff. Local coarse cinder beds (Fig. 2).	Overlain by 80-foot thick tuff-breccia sequence; underlain by 8 feet of tuffs that are underlain by lavas (Fig. 2).
PC-48	Pre-caldera—base of upper breccia sequence; west coast ½ mile south of monument on Bandeera Peninsula.	Same as PC-43.	Similar to PC-43.
PC-84	Pre-caldera—base of upper breccia sequence; east coast, ½ mile NE of bisected tuff cone.	Brownish, poorly consolidated, fine tuff.	Overlain by thin pellet tuff that is overlain by tuff-breccia; underlain by gray ash, a yellow-orange soil, and lava flow.
PC-85	Pre-caldera—within upper breccia sequence; same locality as PC-84.	Coarse, gray, poorly consolidated tuff with numerous large grains, rock fragments, and voids.	Overlain by tuff-breccia; underlain by pumice bed, 1-foot thick.
ID-2	Pre-caldera—base of upper breccia sequence; east coast, north side of Togari Peninsula.	Tuff similar to PC-84.	Overlain by thin tuffs that are overlain by tuff-breccias; underlain by ash, soils, and thick sequence of very fine tuff-breccia (lapilli tuff).
ID-3	Pre-caldera—within upper breccia sequence; specimens from talus blocks on slope.	Coarse, brownish tuff.	Near middle of tuff-breccia sequence; underlain by pumice bed, 1-foot thick.
PC-86	Post-caldera—recent tuff forming surface of terrace ½ mile NE of bisected tuff cone.	Brown, coarse, granular 6-inch tuff layer that is moderately indurated at surface but loose and friable a few inches below.	Overlain by pellet tuffs and locally by beach sands and wash; underlain by mixed loose ash and beach sand.

* See Figure 1.

collection less than 20 different species are distinguishable. Some species are represented by many pieces in various states of preservation.

In most instances the venation of the leaves provides the best distinguishing character. Margins are rarely well preserved and do not help much in identification. General shape, apparent texture, cross section, character of surface, and curvature are sometimes pertinent. It is obvious that with such material it would be hopeless to attempt identification

unless the probable flora were very restricted. The fact that the deposits are considered relatively recent makes reasonable the assumption that the flora was not much different from the present flora of the Marianas. It must be borne in mind, however, that any determination of material of this sort should be regarded as tentative. In the list that follows, those species which were not in any horizon represented by fairly well-preserved material are indicated by question marks. In the lists under the separate sample numbers, species not represented in the known present-day flora are marked by asterisks.

Those remains which presented no features that could suggest any hope for identification have been disregarded. Of the remainder the better specimens in all samples have been retained for deposit in the U. S. National Museum. Of these, all have been identified except two. One of these is probably a leaf scar of a compound leaf, which has not been matched; the other is either a mold of a fruit or an impression of a strongly curved or distorted leaf.

In addition to the specimens collected, molds of tree trunks, probably *Pandanus* judging from the abundant transverse leaf scars surrounding the trunks, were noted in several horizons.

In the following list of species the specimen numbers cited immediately below the name of each species are made up of the collector's sample number with an arbitrarily added number designating material of similar appearance in a sample and letters indicating the various pieces as labelled for deposit in the U. S. National Museum.

POLYPODIACEAE

Pteris quadriaurita Retz.

PC-79-1 (a–f)

Abundant fragmentary leaf impressions showing very clearly the shape and arrangement of pinnules and fairly complete pinnae (Fig. 3).

This fern is widespread in the western Pacific and is found on Pagan today It occurs in shaded places but at times under relatively dry conditions. It is surprising that such a delicate plant should be so well preserved.

PANDANACEAE

? *Freycinetia mariannensis* Merr.

PC-85-3, PC-79-5

PC-79-4 (a–k) (?)

Fragmentary leaf impressions (Fig. 4), very difficult to distinguish from those of *Pandanus tectorius*. Leaf veins 10 to 15 per cm., equally spaced clear to margin, little or no plication apparent, width up to 4 cm. Impressions showing neither plication, rolled margins, nor crowding of veins toward margins have generally been placed here. Some of these, however, where the venation is not clear, could possibly be *Pandanus tectorius*.

This species is found in the well-explored parts of the Marianas as far north as Pagan

FIG. 3. *Pteris quadriaurita*, fragmentary impression of frond showing portion of rachis, pinnae, with pinnules.

FIG. 4. *? Freycinetia mariannensis*, portion of central section of leaf, showing venation.

and Agrigan. It has relatives throughout the Indo-Pacific region. It grows in woods and ravines and is a liana climbing on trees and rocks.

Pandanus tectorius Park.

(*P. fragrans* Gaud., *P. Kafu* Mart.)
PC-79–3 (a–h), PC-79–2 (?), PC-86–4 (a–f), PC-43–4 (a–d), PC-43–10, PC-43–11 (a–c) (?), ID2 (F)-6 (?), ID 2 (F)-2

Abundant fragmentary leaf impressions, many of them showing venation, many showing characteristic plications, some showing curled margins characteristic of dried leaves (as found under the trees), and several representing the narrow prolonged part near tip. Numbers PC-43–11 and ID2 (F)-6 seem to be fragments of the enlarged curved bases of the leaves, but this identification is not certain. Number PC-79–2 seems to be a fragment of an impression of a fruit of this species. This also is not certain. Margins have not been preserved in good condition in any of the material. The veins are generally more crowded especially near the margins, than in *Freycinetia*, varying from about 17 to 26 per cm. depending on the position in the leaf and are closer together toward the apex and near the margins. The veins, except the midrib, are of about equal strength (Fig. 5).

The tree trunk molds seen probably also belong here.

This tree is very common on the Marianas, including Pagan, and is found throughout the tropical Pacific islands, mostly at low altitudes. It is an important component of many forests and is also found scattered in grasslands. Its frequency in this collection could be due both to its abundance and to the hard stiff leaves that lend themselves to preservation as impressions.

FIG. 5. *Pandanus tectorius*, portion of central section of leaf.

GRAMINEAE

Miscanthus floridulus (Labill.) Warb.

PC-43–6 (a–p), PC-43–7 (?), PC-43–8, PC-43–9 (a–b), PC-48, PC-79–7 (a–e), PC-79–8 (a–b), PC-84–1 (a–d), PC-85–1 (a–d), PC-36–5, ID2 (F)-1 (a–k), $ID3_1$-1

Abundant fragments of leaf impressions, as well as a few pieces of stem and leaf-sheath impressions. The leaves are thin and in addition to a heavy midrib have two orders of lesser veins, with the most prominent of these at equal intervals, about 9 to 6 mm. In each interval are 3 to 4 very distinct smaller veins. These blades are mostly 1 to 2 cm. wide, but several are much wider than that, so that it is hard to match them with available herbarium material. However, there seems little doubt that they represent this species. The sheaths show a curved surface, no midrib, and slightly irregular veins, about 16 in 5 mm. A mold of such a sheath shows a slight amount of compression and somewhat of a keel, or angle, as is commonly observed on the back of sheaths in this species. The poorly preserved stem fragments are not especially distinctive.

The leaves of this species are the most abundant fossils in the collection (Fig. 6). In some cases they are arranged so regularly as to suggest the pinnae of a palm or the plications of a fan palm leaf. The venation, however, is very characteristic and is easily matched in herbarium material.

This is the most abundant living plant on Pagan, where it dominates large areas of grassland, especially on loose volcanic ash soils. It is a coarse harsh grass as much as 2 to 3 m. tall. It is found from Japan and the Philippines to New Caledonia and east throughout Micronesia and Polynesia (except Hawaii) on volcanic islands.

PALMAE

Cocos nucifera L.

PC-79-6

This is the impression of a strongly plicate single bent section of a seedling leaf (Fig. 7). The size of the leaf and the amplitude and character of the plications match exactly a segment of a seedling coconut leaf preserved in the Bailey Hortorium of Cornell University. This leaf, if similarly bent, can be fitted into the plications of the fossil. Despite the scantiness of the material this species appears to be reliably identified.

The coconut palm is now very abundant on the island, mostly planted. It is generally regarded as being of human introduction on the oceanic islands of the Pacific, although

FIG. 6. *Miscanthus floridulus*, part of mass of leaf blades, showing venation.

FIG. 7. *Cocos nucifera*, portion of seedling leaf, showing plication.

the possibility of the establishment of drift nuts is not denied. In all probability the present seedling was from progeny of trees introduced by early human visitors to Pagan, indicating that the horizon in which it occurs may be rather recent.

ARACEAE

Alocasia macrorrhiza (L.) Schott

PC-43–1 (a–f), 2, 3, 5

A very well-preserved mold of a petiole, a fragment of the upper part of a petiole, various badly crushed and damaged petiole fragments and a stipule, not especially well preserved. Some of these petiole fragments would have been quite unidentifiable by themselves but were recognized when associated with the other better preserved parts (Fig. 8).

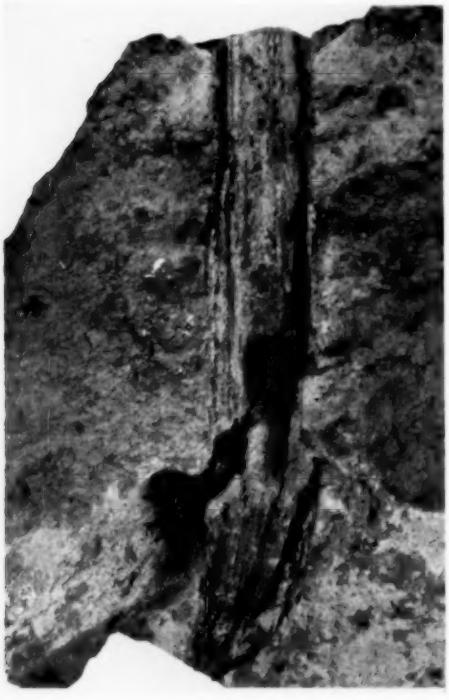

FIG. 8. *Alocasia macrorrhiza*, stipule.

This plant is found throughout the Pacific islands wherever man has carried it. It has not been found where it could not readily have been originally planted by man. The aborigines in many islands are said to utilize it as a famine food, though it is not very palatable. It has no obvious means of getting around unaided, but once established persists and multiplies rather successfully.

Its presence in this fossil flora is distinctly surprising. It indicates that the eruption producing the tuff, which preserved the remains, occurred after the earliest visits by man to the island.

LILIACEAE

? Dianella ensiformis (L.) DC.

PC-85–1, PC-85–2, ID2(F)-3, 4

Leaf blade impressions and fragments of impressions. Where the outline is preserved these taper more strongly than in *Miscanthus;* where venation is evident there is a prominent midrib and fine even venation, the veins of equal thickness, between 3 and 4 per mm. (Fig. 9).

This is not known from Pagan as a living plant, though it may well have been overlooked. It is common elsewhere in the Marianas in swordgrass vegetation on volcanic soils, especially on old erosion scars and around rocky places.

ORCHIDACEAE

? Spathoglottis micronesiaca Schltr.

ID2(F)-7

A reasonably well-preserved impression of a leaf fragment showing strong plication of about the magnitude of that shown by this species, the width and what remains of the shape, also, being correct. The specimen is 3 cm. wide and has just under 3 plications per cm. (Fig. 10).

This species is common in the grassland in the volcanic portions of Guam. It is not known at present on Pagan unless a pink-flowered plant noted but not collected by Bonham is it.

FIG. 9. ? *Dianella ensiformis*, leaf blades.

ULMACEAE

Trema argentea Planch.

PC-79–11

A partial leaf impression with palmate and net venation so perfectly preserved that there is little or no doubt as to its identity with *Trema argentea*. A piece of the opposing part of this impression is preserved on PC-79–12 (Fig. 11).

This plant, which is often and possibly correctly regarded as a variety of *Trema orientalis*, occurs throughout the Marianas, including Pagan, and north through the Volcano and Bonin islands, and with related forms in continental Asia.

It probably may be regarded as one of the few northern elements of the flora of the Marianas; and the present fossil fairly well disposes of the possibility of it being a recent introduction in the Marianas.

FIG. 10. ? *Spathoglottis micronesiaca*, portion of leaf blade showing plication.

HERNANDIACEAE

Hernandia sonora L.

PT-7–1

A portion of an impression of a leaf blade with major veins well shown and with some indication of texture. The appearance of a firm, stiff texture, palmate venation with veins somewhat impressed, and the distance between the base and the first branches from the midvein strongly suggest this species. It is a pantropic lowland or strand tree, common in the Marianas and known from Pagan.

EUPHORBIACEAE

? *Macaranga thompsonii* Merr.

PC-79–12

A poorly preserved impression of part of a leaf showing some major palmate venation.

FIG. 11. *Trema argentea*, portion of leaf, showing venation.

Viewed by itself it would be scarcely identifiable, but when placed side by side with a leaf of this species the correspondence of the venation pattern is striking.

This is a tree commonly found in the southern Marianas, especially in second growth and pioneer situations, but more often on limestone than on volcanic soils. It is not known to be living on Pagan at the present time.

Melanolepis multiglandulosa (Reinw.) Reichenb. f.

PC-86–2

A fragmentary leaf impression showing the main veins The palmate and net venation pattern checks very well with that of this species, which is common on Pagan as in the rest of the Marianas, extending to Indonesia. It grows in thickets and secondary scrub forest.

MELIACEAE

Aglaia mariannensis Merr.

PT-7–3

Several imperfect impressions of leaflets, some showing pinnate venation. The veins are rather straight and strongly ascending. The shape of leaflets of this species varies from elliptic to obovate and that of the fossils shows corresponding variation as much as could be expected in the meager material available (Fig. 12*a*).

This is one of the commonest species of small trees in thickets as well as forests throughout the Marianas, including Pagan. Related species are found elsewhere in Micronesia and westward.

SAPINDACEAE

Tristiropsis obtusangula Radlk.

PC-58–1 (a–e), PT-7–2, 5

Impressions of leaflets, mostly imperfect, apparently somewhat folded along midribs, rather stiff, some of them showing main venation of a pinnate character. Some of the more poorly preserved of these impressions may belong to *Aglaia*, but the oblique bases of most of them scarcely fit that genus (Fig. 13).

Tristiropsis obtusangula is at present known only from Guam and Rota and grows usually but not always on limestone.

TILIACEAE

Elaeocarpus joga Merr.

PT-7–4

A practically perfect leaf impression, obovate, showing a short petiole and some venation (Fig. 12*b*).

This species extends throughout the Marianas as far north as Pagan. In the southern Marianas it grows on limestone but in the north on lava flows. It is a large forest tree. Closely related species are found in other parts of Micronesia and the Philippines.

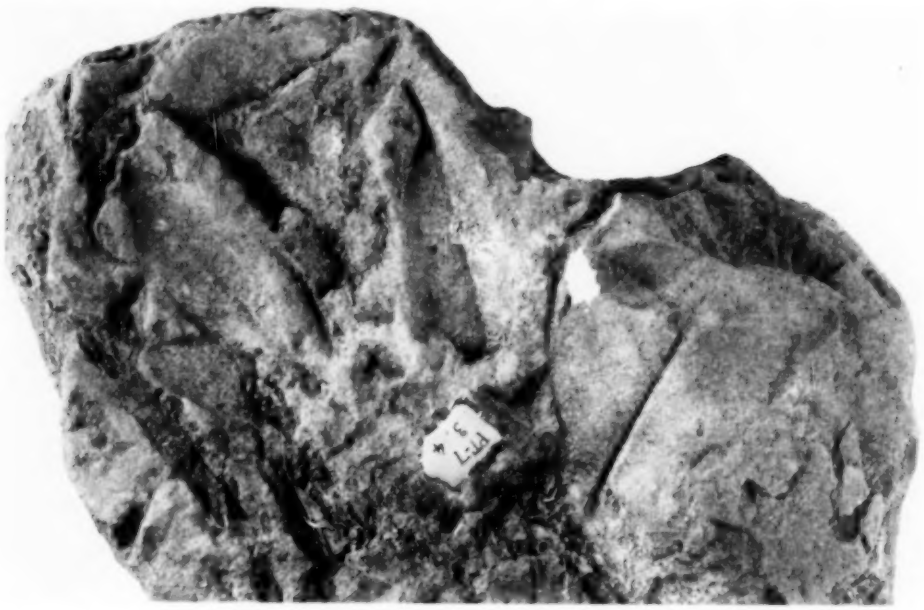

Fig. 12. *Aglaia mariannensis*, impression on right, base of large leaflet, that on left, possibly one of smaller leaflets. *Elaeocarpus joga*, impression in center, leaf blade and petiole.

THEACEAE

? Eurya nitida Korth.

PC-79-10

Two fragmentary leaf impressions, not positively identifiable. Only bases, with some obscure venation, and rather curious minute surface marking are available. *Eurya* seems the most likely identity.

This is a small-leafed shrub or small tree, characteristic of volcanic soils and frequently found isolated or in small thickets in swordgrass areas. It has been reported from Pagan by Hosokawa as *Eurya ladronica* Hosokawa.

VERBENACEAE

Premna obtusifolia R. Br.

PC-86-1

A good leaf impression with venation rather clearly shown but lacking the apex (Fig. 14). It is much smaller than the average for this species but matches well enough some of the smallest leaves present on available herbarium material. The angle of divergence of the main veins is so wide as to preclude its belonging to most of the other Micronesian species with palmate venation, the only possibilities being *Thespesia populnea* (L.) Sol. ex Correa, which it does not resemble in other characteristics and which is rarely so small, and *Sida fallax* Walp., which has never been reported from the Marianas.

Premna obtusifolia is a very common tree throughout the Marianas, including Pagan, growing in thickets or secondary growth as well as in original forest. The species is variable and extends over much of the Indo-Pacific region. It has been given various names, the one most commonly used for Marianas material being *Premna gaudichaudii* Schauer.

FIG. 13. *Tristiropsis obtusangula*, impression of leaflet, showing texture and venation.

FIG. 14. *Premna obtusifolia*, an unusually small leaf blade, with apex missing, showing venation.

Family unknown

Unidentified impression, probably a leaf scar.

ID2(F)-5

This is a concave impression, more or less shield shaped, with 5 (or 6) bundle traces.

Unidentified mold of a fruit or curved leaf.

PC-86-3

This hollow curved impression, lacking suggestive details, was not matched with anything.

PALEOECOLOGY

By listing the species identified from each of the samples it is possible to suggest something of the probable ecological conditions and vegetation types at the time the various deposits represented were laid down. Such conclusions are, of course, extremely tentative when based on so few species. It is greatly hoped that at some future time more extensive collecting may be done in these beds so that the picture of the past vegetation and conditions on the island may become clearer.

Sample PC-43

Pandanus tectorius, *Miscanthus floridulus*, *Alocasia macrorrhiza*

It is hard to associate *Alocasia* with swordgrass except where the *Alocasia* might have been in a somewhat shaded ravine bottom, perhaps with *Pandanus* trees, and with the sides of the ravine covered with swordgrass, possibly extending down almost to the bottom of the ravine. On more level ground, if it is not too dry, the *Alocasia* could have grown in a thicket of *Pandanus* and possibly other trees, closely surrounded by swordgrass. The *Alocasia* suggests the presence or former presence of man, as this plant was in all probability distributed in the Pacific islands entirely through human agency.

Sample PC-48

Miscanthus floridulus

Probably swordgrass vegetation.

Sample PC-58

**Tristiropsis obtusangula*

This is a forest tree, not now found on

* Not now known to be living on Pagan.

Pagan or in the northern Marianas but common on rough limestone on Guam. An association of plants similar to that in which this species grows on Guam occurs on rough lava in the northern Marianas on Alamagan Island, which is much like Pagan. Something like this association may have existed on rough lava in pre-caldera time on Pagan.

Sample PC-79

*Pteris quadriaurita, Pandanus tectorius, Freycinetia mariannensis, Miscanthus floridulus, Cocos nucifera, Trema argentea, ? *Macaranga thompsonii, ? Eurya nitida*

From the assemblage of plants represented here the habit could have been the margin of a mixed thicket, possibly second growth, bordering on swordgrass. The presence of a seedling coconut suggests the possibility of human disturbance.

Sample PC-84

Miscanthus floridulus

The vegetation indicated is swordgrass.

Sample PC-85

*? Freycinetia mariannensis, Miscanthus floridulus, *Dianella ensiformis*

Swordgrass vegetation close to either a thicket or a rock cliff, unless what are here identified as *Freycinetia* leaves are really *Pandanus*, in which case it would have occurred as scattered trees or thickets in the swordgrass.

Sample PC-86

Pandanus tectorius, Miscanthus floridulus, Melanolepis multiglandulosa, Premna obtusifolia

Unidentified mold.

Probably swordgrass with mixed thickets or patches of scrub forest of *Pandanus* and broad-leafed trees.

Sample PT-7

*Hernandia sonora, Aglaia mariannensis, Elaeocarpus joga, ? *Tristiropsis obtusangula*

This association suggests a forest of the sort that grows on rough lava on such islands as Alamagan at the present day, or on rough limestone on the islands farther south.

Sample ID2 (F)

*Pandanus tectorius, Miscanthus floridulus, *Dianella ensiformis, *Spathoglottis micronesiaca*

Unidentified leaf scar or fruit impression.

The conditions suggested by this small flora are those of swordgrass, possibly somewhat sparse, with either thickets or scattered trees of *Pandanus*.

Sample ID3$_1$

Miscanthus floridulus

Probably swordgrass vegetation.

From the foregoing lists it will be seen that there is meager evidence for any comprehensive opinions on the past vegetation of Pagan. Most of the indications are that at least some of the vegetation was much the same as that found on the island today. Swordgrass occurs in all but the two lowest horizons, and there is little doubt that it dominated the vegetation wherever there was a loose ash substratum. Undoubtedly there were scattered trees or clumps of *Pandanus* and probably mixed thickets and scrub forest of *Pandanus* and other trees. Although the coconut does not appear in most of the lists of species, it may very well have been present in all of the later horizons, as there is little doubt that it was introduced by the early Chamorros and no reason why it would not have persisted whether or not they inhabited the island for any great length of time. An interesting fact is the complete lack of *Casuarina* in the collections. Next to *Miscanthus* it is the most abundant component of the modern vegetation of the island. It adds to the scanty evidence that *Casuarina* may be a recent arrival in the Marianas, but this is still an unsettled question.

The two lowest horizons, with plants commonly found on rough lava or rough limestone and with one tree not known today on Pagan, possibly represent a slightly more mature vegetation than any known at present on the island, though it may actually be represented in the mixed forest type. Something like it is prominent on extensive rough lava

flows on Alamagan, the next island to the south of Pagan. The violent explosive eruptions that formed the calderas and deposited the thick tuffs may have completely destroyed the stands of this type of forest.

The presence of four species in the fossil collections that are not known to be living on the island today may possibly have little significance, for the living flora has not been really well collected and those species may actually be present now. However, on an island with frequent and at times violent volcanic activity the continued existence of any but the most tenacious species of plants is hazardous, and it is more than likely that some that were once growing on Pagan may have been eliminated.

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Vascular Flora of Pagan Island, Northern Marianas[1]

F. R. Fosberg[2]

The island of Pagan is composed of two active volcanic mountains connected by a low isthmus. It is situated at about the center of the chain of young volcanic islands that make up the northern half of the Marianas at 18° 6′N., 145°45′E. Its flora is not very well known, and doubtless a fair number of species remain to be found there. In connection with the preparation of reports on the geology of the island (Corwin, *et al.*, ined.) and on a collection of fossil plants (Fosberg and Corwin, 1958) it has been necessary to bring together as completely as feasible the records of vascular plants found there to date.

Few botanical collectors have visited Pagan. Perhaps the first was A. Marche, who made general collections during a voyage to the Marianas in 1887 to 1889. There are a few specimens from Pagan in his collection which is at the Museum d'Histoire Naturelle in Paris. No comprehensive report on his plants has ever been published, and most of the specimens are only now being identified. It is not possible at this time to compile a complete list of his Pagan specimens, but those available are included here. The next visitor who left any botanical records was the German governor, G. Fritz, who made a voyage to the northern Marianas in 1901. He noted a few of the prominent plants, especially cultivated ones, and planted trees of several kinds on the various islands. His records, though not supported by specimens, are indicated in the following list by the symbol **Fr** in boldfaced type.

A long period with no botanical work on the island followed until the early 1930's, when the Japanese botanists became very active in Micronesia. In 1933 Prof. Ryôzô Kanehira made a short visit to Pagan, collecting a few specimens, several of which he reported in 1934 and the others in 1935. Prof. T. Hosokawa made two short visits in July and August, 1934, during which 42 plants were gathered. In 1934 he listed his own and previous records from all the Marianas, listing the islands for each species.

In 1949, under the auspices of the Pacific Vegetation Project, Mr. Donald Anderson spent a few days on the island and collected a fair number of species. A set of these will be deposited in the U. S. National Herbarium and others in the Bernice P. Bishop Museum and the New York Botanical Garden. In 1950, I was able to spend a day on the island and collected a number of specimens, sets of which will be deposited in the same herbaria. During a geological study of the island in the summer of 1954, Mr. L. D. Bonham, of the U. S. Geological Survey, collected 40 specimens in order to obtain identifications of plants mentioned in his account of the vegetation (in Corwin *et al.*, in preparation). His specimens will be deposited in the U. S. National Herbarium. One sight record by G. L. Corwin is included.

On the basis of these collections and records there are at present 168 species and varieties of vascular plants known from the island, 101 of which are probably indigenous, 8 (at least) of aboriginal introduction, and 59 probably of post-European introduction. In addition to these, 4 other species are recognized only as fossils (Fosberg and Corwin, 1958). In the following list specimens are not

[1] Publication authorized by the Director, United States Geological Survey. Manuscript received September 15, 1955.

[2] United States Geological Survey, Washington 25, D. C.

cited, as I plan to publish an annotated catalog of the flora of Micronesia, in which all specimens seen will be cited. Neither a description of the island nor of its vegetation are included as these will be given in a paper on the fossil plants (Fosberg and Corwin, 1958). After each species the workers who have recorded or collected it on Pagan are designated by the following symbols in bold-faced type:

Marche	**M**
Fritz	**Fr**
Kanehira	**K**
Hosokawa	**H**
Anderson	**A**
Fosberg	**Fo**
Bonham	**B**
Corwin	**C**

The nomenclature is that presently accepted by me and not necessarily that under which the original reports were made.

The indigenous flora is almost entirely an attenuation of that of the Marianas group to the south, some of the species extending northward to the Bonin Islands. *Trema argentea* and *Myoporum boninense* may possibly be plants that have spread from the Bonin Islands southward in prehistoric time, though a spread in the opposite direction is entirely possible, as both species are known from Saipan. *Fimbristylis urakasiana* has previously been regarded as endemic on Uracas, the northernmost of the Marianas. It is very likely present at least on all of the recent volcanic islands of the group, but they have not been adequately enough studied and collected to detect all plants present, especially in such groups as *Fimbristylis*. Of the species and varieties, both recent and fossil, 20 are probably endemic to the Marianas and 3 more to the Mariana, Volcano, and Bonin islands. The remainder are widespread species, mainly of lowlands and strands of the Indo-Pacific area, a few of them almost pantropic. These figures are probably valuable only as a general indication of the distributional relations on a rather young volcanic island. When more complete collections have been made, both on Pagan and on the other northern Marianas, more reliable and significant conclusions may be reached as to the origin of the flora of this area.

SYSTEMATIC LIST OF SPECIES

* Indicates recently introduced species; † indicates species believed to be of aboriginal introduction.

Gleichenia linearis (Burm. f.) C.B.Cl. **Fo**
Cheilanthes tenuifolia (Burm.) Sw. **H, Fo**
Acrostichum aureum L. **H, Fo**
Asplenium laserpitiifolium Lam. **H**
Asplenium nidus L. **A**
Asplenium unilaterale Lam. **H**
Davallia solida (Forst. f.) Sw. **H, A**
Dryopteris unita (L.) O. Ktze. **Fo, B**
"Lastrea" torresiana (Gaud.) Moore **A, Fo**
Nephrolepis hirsutula (Forst. f.) Presl **H, A, Fo, B**
Polypodium scolopendria Burm. f. **H, Fo, B**
Pteris quadriaurita Retz. **H, Fo**
Sphenomeris chinensis (L.) Maxon **Fo**
Psilotum nudum (L.) Griseb. **H**
Freycinetia mariannensis Merr. **H, A**
Pandanus dubius Spr. **H**
Pandanus tectorius Park. **K, H, A, B**
***Cenchrus brownii** R. & S. **A**
***Cenchrus echinatus** L. **A**
***Chloris inflata** Link **B**
Chrysopogon aciculatus (Retz.) Trin. **A, Fo, B**
***Cynodon dactylon** (L.) Pers. **A, B**
***Dactyloctenium aegyptium** (L.) Willd. **H, A, Fo, B**
***Digitaria ciliaris** (Retz.) Koel. **Fo**
***Eleusine indica** (L.) Gaertn. **A, Fo**
***Eragrostis amabilis** (L.) W. & A. **H, A, Fo**
Heteropogon contortus (L.) Beauv. **A, Fo**
Miscanthus floridulus (Labill.) Warb. **H, K, A, B**
Panicum ambiguum Trin. **A, Fo**
***Paspalum conjugatum** Berg. **Fo**
Paspalum orbiculare Forst. f. **A, Fo**
***Pennisetum purpureum** Schumach **Fo**
Sporobolus virginicus (L.) Kunth **A, B**
Thuarea involuta (Forst. f.) R. & S. **H**
***Zea mays** L. **Fr**

Zoysia tenuifolia Trin. A, Fo
*Cyperus compressus L. A, B
Cyperus cyperinus (Retz.) Vahl. A
Cyperus javanicus Houtt. A, Fo
Cyperus polystachyos Rottb. Fo
Fimbristylis annua (All.) R. & S. A
Fimbristylis cymosa R. Br. A
Fimbristylis urakasiana Kük. Fo
Scleria lithosperma (L.) Sw. A
†Alocasia macrorrhiza (L.) Schott H, Fo, B
†Colocasia esculenta (L.) Schott Fo
*Xanthosoma sagittifolia Schott A
†Areca cathecu L. C
†Cocos nucifera L. Fr, B
*Ananas comosus (L.) Merr. Fr, A, Fo, B
*Agave americana L. B
*Agave sisalana Perr.? A
Dianella ensiformis (L.) DC. (Fossil only)
*Crinum sp. H
Curculigo orchioides Gaertn. H, K
*Hymenocallis littoralis (Jacq.) Salisb. A, B
†Tacca leontopetaloides (L.) O. Ktze. H, A
†Musa sapientum L. Fr, H, B
Spathoglottis micronesiaca Schltr. (Fossil only)
Taeniophyllum mariannense Schltr. H
Casuarina equisetifolia L. Fr, H, A, Fo, B
Trema argentea Pl. H, K, A, Fo
Boehmeria celebica B. H
Pipturus argenteus (Forst. f.) Wedd. H, A, B
†Artocarpus altilis (Park.) Fosb. Fr, H, A, B
Ficus prolixa var. carolinensis (Warb.) Fosb. H, A, Fo, B
Ficus tinctoria var. neo-ebudarum (Summ.) Fosb. H, A, Fo, B
*Achyranthes aspera L. H
*Amaranthus spinosus L. Fo
Boerhavia diffusa L. H
Sesuvium portulacastrum L. A
*Portulaca oleracea L. A, Fo
Portulaca samoensis var. Poelln. H, A, B
Guamia mariannae (Saff.) Merr. K, H, K, A
Cassytha filiformis L. H
Hernandia sonora L. H
Capparis cordifolia Lam. A
Abrus precatorius L. M, H, A, Fo
Canavalia sericea Gray H, B
Cantharosperumum scarabaeoides (L.) Bail. H
*Cassia lechenaultiana DC. K, A
*Cassia occidentalis L. A, Fo
*Cassia tora L. H
*Crotalaria mucronata Desv. A, Fo
*Crotalaria trifoliastrum Willd. H, H
*Delonix regia (Boj.) Raf. B
*Desmodium triflorum (L.) DC. H, A, Fo
Erythrina variegata var. orientalis (L.) Merr. H, A
Glycine clandestina Wendl. H, H
Mucuna gigantea (Willd.) DC. A
Mucuna pruriens (L.) DC. H
*Pithecellobium dulce (Roxb.) Benth. K, A, B
Vigna marina (Burm.) Merr. H, K, A
*Citrus sp. C
*Euphorbia hirta L. H, K, A, Fo
*Euphorbia prostrata Ait. Fo, B
*Euphorbia thymifolia L. A, Fo
*Jatropha curcas L. A
*Jatropha gossypifolia L. A, Fo, B
Macaranga thompsonii Merr. (Fossil only)
*Manihot esculenta Crantz A
Melanolepis multiglandulosa var. glabrata (M.-A.) Fosb. H, Fo, B
Phyllanthus mariannensis M.-A. H, K
*Phyllanthus niruri L. A, Fo
Aglaia mariannensis Merr. H, A, Fo
*Mangifera indica L. B
Tristiropsis obtusangula Radlk. (Fossil only)
Colubrina asiatica (L.) Brongn. H, A
Elaeocarpus joga Merr. H, K
Grewia crenata (L. f.) Schinz & Guill. M, H, A, Fo
*Triumfetta semitriloba Jacq. A
*Gossypium hirsutum L.? A, B
Hibiscus tiliaceus L. H, A, Fo, B
*Sida acuta Burm. f. H, A, Fo
*Sida rhombifolia L. M, H, Fo
Thespesia populnea (L.) Sol. A
Urena lobata L. H
*Ceiba pentandra (L.) Gaertn. A
Melochia sp. A
Calophyllum inophyllum L. A
Ochrocarpos odoratus (Raf.) Merr. H
Eurya nitida Korth. H
*Carica papaya L. A, Fo

*Passiflora foetida var. hispida (DC.) Killip. A, Fo, B
Pemphis acidula Forst. H, A
Terminalia catappa L. H, A
Eugenia reinwardtiana DC. A
*Psidium guajava L. A
Barringtonia asiatica (L.) Kurz H, A, B
Melastoma malabathricum L. Fo
Polyscias grandifolia Volk. H, A
*Polyscias scutellaria (Burm. f.) Fosb. Fo
Centella asiatica (L.) Urb. H
Lysimachia mauritiana Lam. H, H
Discocalyx megacarpa Merr. H
Pouteria obovata (R. Br.) Baehni H, A
Geniostoma micranthum DC. K
Jasminum marianum DC. A
Bleekeria mariannensis (A. DC.) Koidz. K, H, K, A
Cerbera dilatata Mgf. H, A
Ochrosia oppositifolia (Lam.) K. Schum. H, A, B
*Thevetia peruviana (Pers.) Merr. A, Fo
*Ipomoea aquatica Forsk. Fo
*Ipomoea batatas (L.) Poir. Fr, A, Fo
Ipomoea pes-caprae (L.) Sweet H, A, Fo, B
Operculina ventricosa (Bert.) Peter M, Fo
Heliotropium ovalifolium var. depressum (Cham.) Merr. Fo
Messerschmidia argentea (L. f.) Johnst. H
*Hyptis pectinata (L.) Poir. Fo
*Hyptis capitata Jacq. H
*Hyptis suaveolens Poir. H
Callicarpa candicans (Burm. f.) Hochr. H, A
Callicarpa lamii Hosok. M, A
Premna obtusifolia R. Br. H, K, A, Fo, B
*Stachytarpheta indica (L.) Vahl A, Fo
Vitex negundo L. H
Myoporum boninense Koidz. A
Hedyotis foetida var. mariannensis (Merr.) Fosb. H, A
*Morinda citrifolia L. H, A, B
Psychotria mariana Bartl. H, K, A, Fo, B
Randia cochinchinensis (Lour.) Merr. A
Scaevola frutescens (Mill.) Kr. H, A
*Ageratum conyzoides L. Fo
*Elephantopus mollis H. B. K. K, A, Fo
*Emilia sonchifolia (L.) DC. A, Fo
Glossogyne tenuifolia Cass. H, K, Fo
*Synedrella nodiflora Gaertn. H, K
*Vernonia cinerea (L.) Less. H, A, Fo
Wedelia biflora (L.) DC. H, A, Fo
Wedelia biflora var. canescens (Gaud.) Fosb. A

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Oceanographic and Meteorological Aspects of the Gulf of California[1]

GUNNAR I. RODEN

THE PRIMARY OBJECT of the present paper is to give an adequate description of the climatic and oceanographic conditions in the Gulf as they are known today.

Only a few authors have discussed the Gulf (Sverdrup, 1940; Osorio Tafall, 1944) and only the geological work was described in detail (Anderson, 1950; Durham, 1950; Natland, 1950; Revelle, 1950; Shephard, 1950).

The data used in the present investigation are largely taken from the "E. W. Scripps" expeditions in 1939 (Sverdrup and staff, 1943) and from the publications of the Servicio Meteorológico Mexicano, the U. S. Coast and Geodetic Survey, and the U. S. Hydrographic Office.

The data for the Gulf are few and the conclusions that can be drawn from them are necessarily limited and should be taken only as a first approximation until more and better data are at hand.

The Gulf of California is of considerable interest both scientifically and economically, and it is expected that its importance will steadily increase in the future, especially as an additional food source for Mexico. A thorough knowledge of the physical and chemical changes taking place in the Gulf is essential to the understanding of its fisheries.

Moreover, the Gulf is interesting because it represents the only large evaporation basin of the Pacific Ocean and because it shows certain differences from other comparable evaporation basins. A final answer to all the different problems in the Gulf cannot be expected from the meager data available but it is the hope of the author that this paper may stimulate more research in this intriguing area.

ACKNOWLEDGEMENTS

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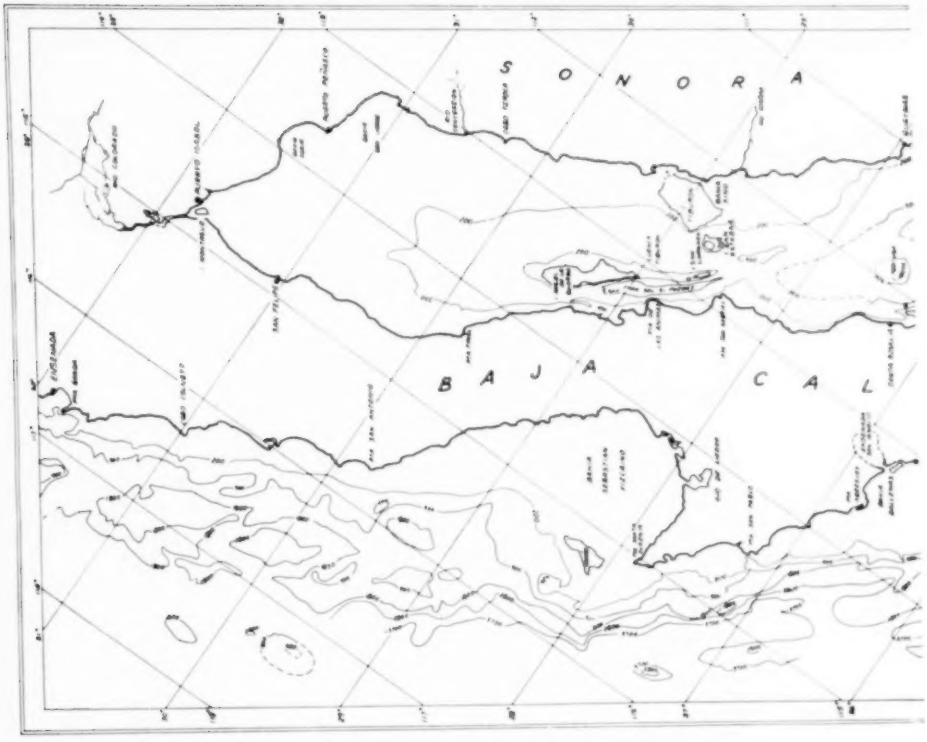

FIG. 1. Bathymetric map of the Gulf of California.

GENERAL DESCRIPTION AND PREVIOUS INVESTIGATIONS

The Gulf of California is unique in many respects. Lying as it does in a predominantly arid region it comprises the only large evaporation basin of the Pacific Ocean. It is roughly rectangular in shape and lies between the Mexican states of Baja California to the west and of Sonora and Sinaloa to the east. At its southern end the Gulf is in open communication with the ocean. The length of the Gulf is about 1400 km. and the average width about 150 km., giving a total surface area of roughly 210,000 km.^{2}, if the southern boundary is taken along latitude 23°N. Between this latitude and a line joining Cabo San Lucas with Cabo Corrientes (Fig. 10) lies a transition region which occasionally is influenced by Gulf water (Schott, 1935). This region will be called the Gulf Entrance, and it has a total surface area of roughly 40,000 km.^{2}

Topographically the Gulf can be divided into a number of basins, separated from each other by transverse ridges. The deepest basins have a maximum depth of more than 3000 m. and a sill depth below 1500 m. (Geol. Soc. Amer., Mem., 1950). In the northern part of the Gulf isolated basins are found in which different hydrographic conditions prevail (Sverdrup, 1941). These basins seem to represent deep depressions in an otherwise quite narrow shelf and are completely isolated below 200 to 300 m. Their isolated character is quite sufficient to explain the hydrographic conditions found in them and it is not neces-

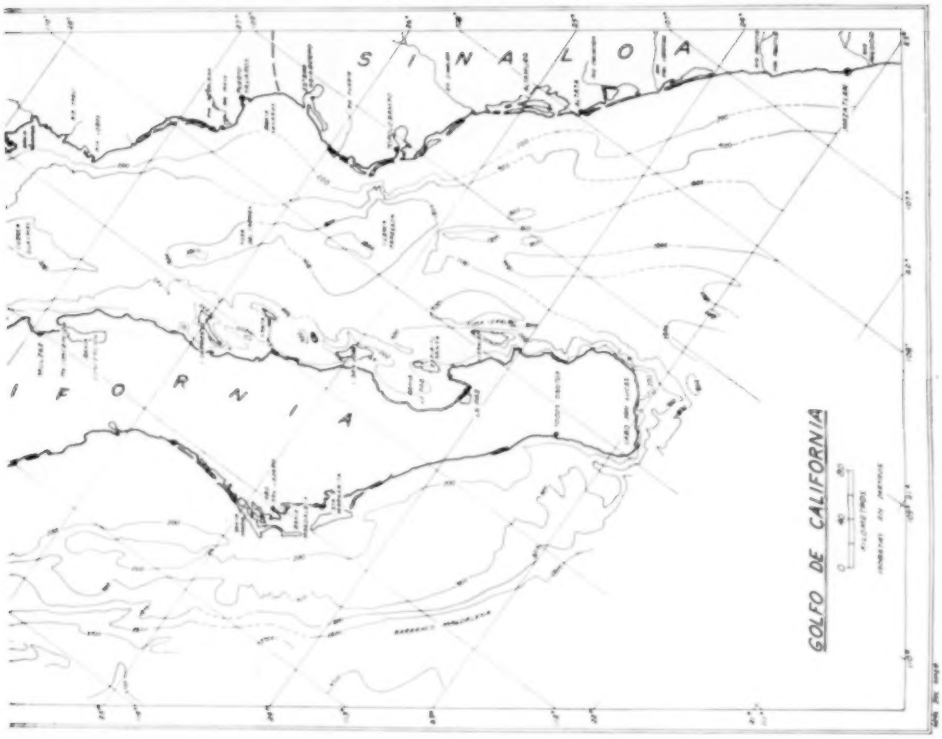

FIG. 1. Bathymetric map of the Gulf of California (*continued*).

sary to assume the existence of a ridge running SSE between Angel de la Guarda and Tiburón to account for the differences (Sverdrup, 1941). There are two large islands in the Gulf—Angel de la Guarda and Tiburón—both with elevations exceeding 1500 m.

The coast along Baja California is very steep and flanked by numerous islands and rocks. Off Rio Colorado and northern Sonora the coast is less rugged and possesses a wide shelf. Along Sinaloa the shelf narrows again and disappears at Cabo Corrientes.

The Gulf remained scientifically unknown until fairly recent times. Prior to the coming of the conquistadores, the Gulf area was inhabited by different Indian tribes who lived by fishing and undoubtedly had some local knowledge of the currents and the general appearance of the water. Their observations are, however, lost because they had no written records.

With the coming of the Spaniards, trade developed between Gulf ports and the Far East (Hakluyt, 1598) and various captains entered the Gulf with lead and line. The first written records are therefore found in the ships' logs of the early seafarers. Scientific exploration began in 1889 when the U. S. Fish Commission steamer "Albatross" (Fig. 2) entered the Gulf to make a few hydrographic stations, especially in the northern part (Townsend, 1901). The data collected at these stations consisted of temperature and density determinations, the latter being made with a hydrometer. The results of the expedition (not previously published in this form) are shown in Figure 3.

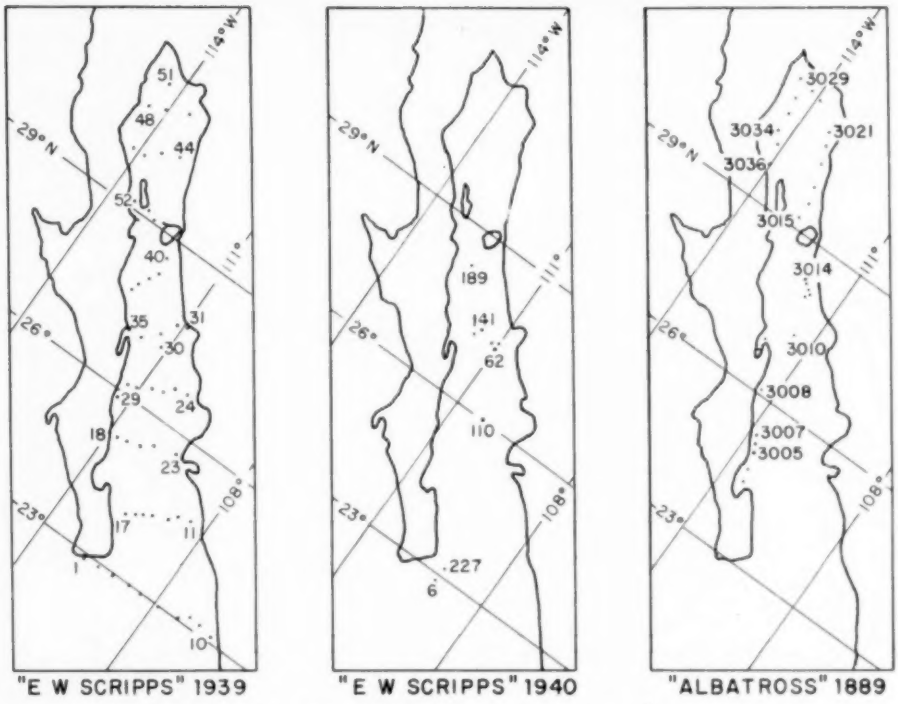

FIG. 2. Stations occupied on previous expeditions.

Considerable warming and high salinity were found in shallow bays such as Bahia Guaymas and Bahia Concepcion. Upwelling was characteristic along the northern coast of Sonora where the temperature was about one degree lower and the salinity 0.4‰ lower than in the neighborhood offshore. Near the mouth of Rio Colorado the salinity varied between 35.2 and 35.7‰, probably due to the admixture of fresh water. The bottom temperatures in the northern part everywhere exceeded 11°C. and the bottom salinity varied between 35.5 and 36.1‰.

The next important description of the Gulf of California was made by Thorade (1909) in a paper on the California Current. He examined a great number of ship logs over many years and was the first investigator to draw monthly surface temperature charts (Fig. 4) for the southern part of the Gulf and deduce from them the general circulation in the Gulf and to correlate the sea surface temperatures to the direction of the wind, the orientation of the shore line, and the special climatological conditions prevailing in the Gulf. His main conclusions were that the temperature of the Gulf is independent of the temperature in the adjacent ocean and that the low temperatures along the east coast in winter are the result of northerly winds that tend to transport surface water away from the coast and thus produce upwelling. He also observed correctly that during most of the year the circulation is counterclockwise in the Gulf and that the water enters the Gulf along the east coast and leaves it along the west coast. He mentioned that "manifold discontinuities are observed by a sudden change in tem-

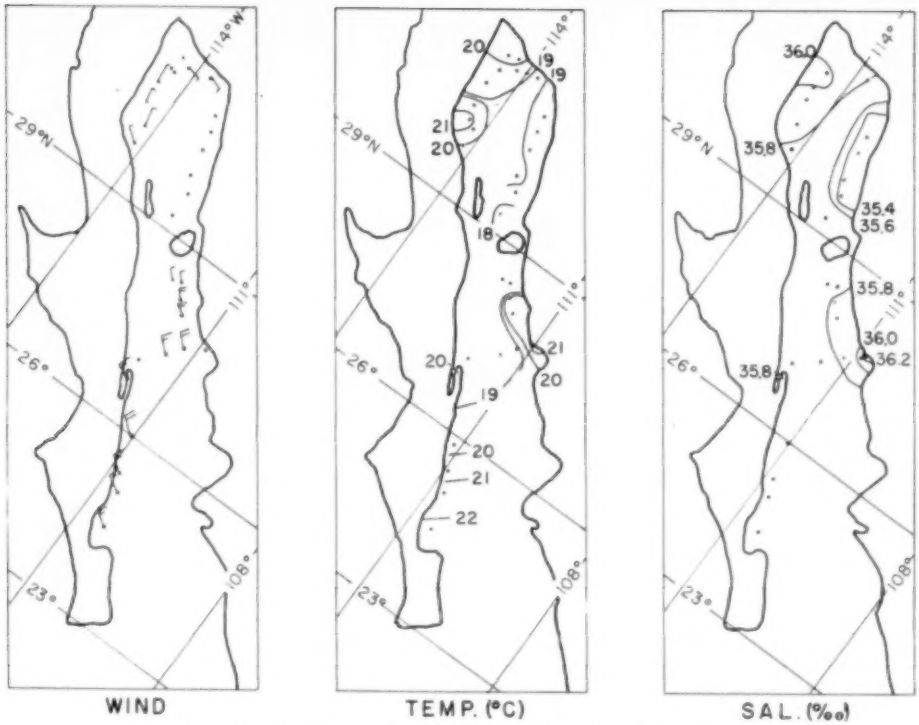

FIG. 3. Distribution of winds, temperature, and salinity in March, 1889.

perature" in the vicinity of Cabo San Lucas, which might well have been the first description of the San Lucas front.

Schott (1935: 208) described the Gulf of California as part of the Mexican region, a region defined roughly as lying between the Gulf of Tehuantepec and Cabo San Lucas and extending seaward between the California Current and the North Equatorial Current. The Mexican region is characterized by a very high surface temperature and very weak circulation. He briefly mentioned the temperature discontinuity near Cabo San Lucas and drew attention to the frequent hurricanes in that region.

In the spring of 1939 the Scripps Institution of Oceanography sent an expedition into the Gulf led by H. U. Sverdrup on the "E. W. Scripps." Fifty-three stations were made in the Gulf (Fig. 2) taking temperature, salinity, oxygen, calcium carbonate and plankton observations on each station from the surface to the bottom (Sverdrup and staff, 1943). These data are still the most complete ever taken in the Gulf. Sverdrup's main conclusions were that the Gulf can be subdivided into two parts, a northern part and a southern part, separated from each other by a submarine ridge which comes to within 200 m. below the surface. The water mass to the north is largely of local origin and formed by convective currents in winter, the water to the south is nearly the same as in the adjacent ocean and only modified slightly at the surface by extensive evaporation (Sverdrup, 1941).

In late fall of 1940 the "E. W. Scripps" made a second trip to the Gulf. The chief

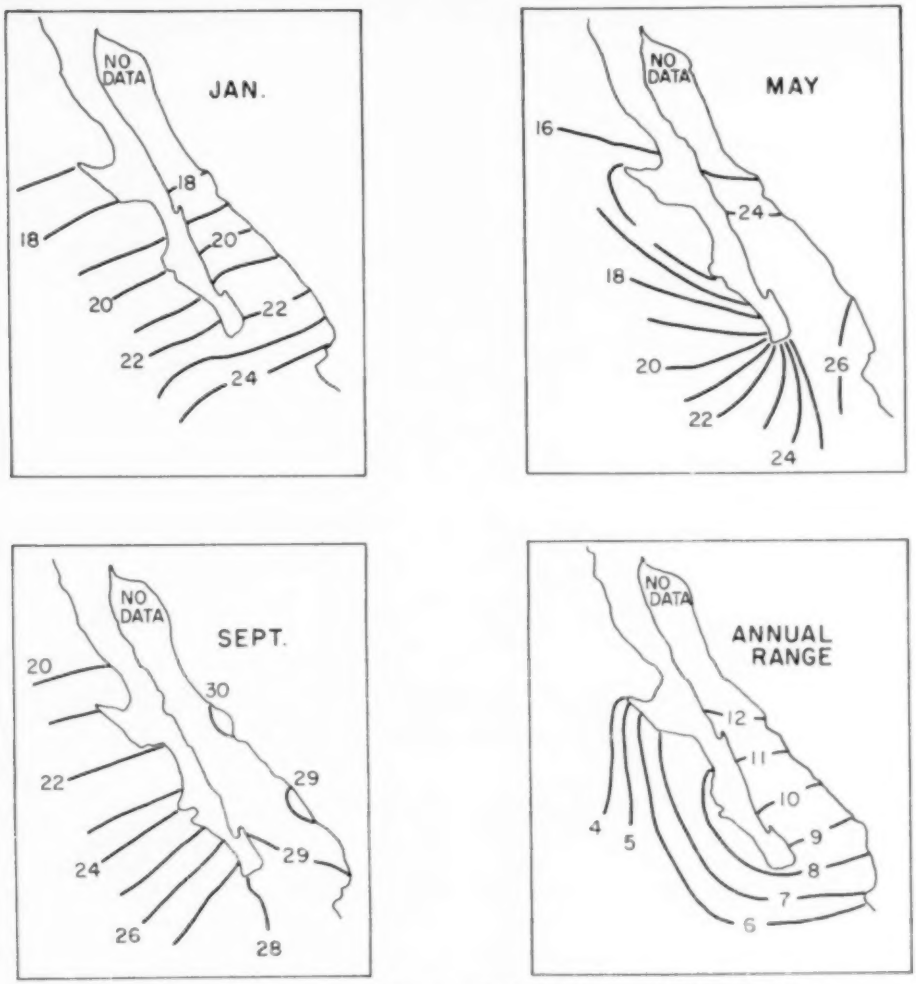

FIG. 4. Sea surface temperatures (°C.) in the Gulf of California. (After Thorade, 1909.)

aim was geological (Geol. Soc. Amer., Mem., 1950) but a few hydrographic stations were made (Fig. 2). Silicate and phosphate were measured for the first time in the Gulf, but the methods used in determining the concentrations do not warrant a detailed description of them. A brief account on the silicate distribution in the Gulf was given by Sverdrup (Sverdrup and staff, 1940). In 1944 the Mexican government sponsored a brief study of the Gulf in order to determine the feasibility of a minor guano industry (Osorio Tafall, 1944). The industry was never started. In 1956 the U. S. Fish and Wildlife Service has planned two expeditions into the Gulf to study the distribution of sardine eggs and larvae and to make frequent hydrographic stations, which undoubtedly will bring back new and valuable data for further scientific investigations.

CLIMATOLOGY

The great differences in climatic conditions observed in the Gulf as one proceeds from northwest to southeast, covering nearly nine degrees of latitude, and the differences that exist between the east side and the west side of the Gulf, are closely related to the atmospheric circulation and to the existence of mountain ranges that modify this circulation.

The influence of the Pacific Ocean upon the climate of the Gulf is greatly reduced by a nearly unbroken chain of mountains, 2000 to 3000 m. high, in Baja California. The considerable differences in temperatures and precipitation between the Pacific side and the Gulf side have already been mentioned by Thorade (1909) and are fully confirmed by data collected by the Servicio Meterologico Mexicano (Boletin Anual). Along the Pacific side of the peninsula the air temperatures are never excessively high and precipitation falls during the winter season in the northern part, and during the summer season in the southern part, with annual amounts around 200 mm. Along the Gulf side air temperatures are very high in summer and rather cool in winter. In the north all the precipitation falls in summer. The amount of rainfall (Table 1) varies between traces in the north and 200 mm. at the southern tip of Baja California, which is crossed by the Tropic of Cancer. The rainfall on the corresponding latitude on the eastern side of the Gulf amounts to 400 mm. per year.

On the average the west coast of the Gulf receives only half as much rain as the east coast. In Sonora the winter is cool and the summer hot. Precipitation falls from July to September, varying between traces in the northernmost part and 251 mm. in Guaymas. In Sinaloa the winter is warm and the summer less hot than in Sonora. Precipitation falls from August to October, with amounts between 300 mm. in the north and 850 mm. in Mazatlán (Table 1). From the discussion of the precipitation figures it becomes evident that the Gulf of California is far from being situated in a desertlike environment.[2] The vegetation in Baja California and Sonora is of

[2] Most Americans call northern Sonora and Baja California a desert, though people from North Africa and South America would consider this region a dry steppe.

TABLE 1

MEAN MONTHLY AIR TEMPERATURE AND PRECIPITATION 1921–1935 (SERV. MET. MEX., BOLETIN ANUAL)

	WEST COAST (IN GULF)				EAST COAST (IN GULF)				EAST COAST (OUTSIDE GULF)			
	Mulege (26°53′N–112°00′W)		La Paz (24°10′N–110°18′W)		Guaymas (27°55′N–110°53′W)		Topolobampo (25°36′N–109°03′W)		Mazatlán (23°11′N–106°25′W)		Cabo Corrientes (20°24′N–105°43′W)	
	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.
January	14.0	2.6	18.2	3.2	17.7	7.9	18.6	6.4	19.3	11.0	23.2	19.5
February	16.0	3.4	19.2	11.4	18.9	6.3	19.7	6.6	19.4	9.7	22.9	29.6
March	17.8	0.1	21.3	0.8	20.7	4.6	20.1	6.4	19.7	3.4	22.7	1.3
April	20.1	0.2	23.2	0.2	22.8	3.0	22.2	tr.	21.3	0.1	23.9	tr.
May	22.9	0.1	25.5	tr.	25.5	2.8	25.0	1.8	23.8	1.8	25.4	2.3
June	27.2	tr.	27.2	0.2	28.8	0.7	29.1	5.3	26.4	29.2	26.7	57.3
July	30.5	6.1	30.0	6.3	30.7	46.7	29.8	39.9	27.5	166.9	28.9	145.0
August	30.4	16.8	30.3	41.7	30.5	75.5	29.7	100.6	27.6	241.8	27.9	272.1
September	29.0	40.0	29.0	51.9	30.2	54.4	29.7	55.9	27.5	268.6	27.5	307.0
October	24.6	5.4	27.0	9.6	27.3	9.5	27.8	73.7	26.7	61.6	27.5	91.0
November	19.5	6.8	23.2	13.4	22.6	11.1	24.0	7.0	23.5	11.7	26.1	15.2
December	14.9	19.2	20.0	34.3	18.6	28.9	19.7	55.3	20.6	44.4	23.8	13.5
Year	22.2	101.1	24.4	173.0	24.5	251.4	24.6	358.9	23.6	850.2	25.5	953.8
Minimum	0.0	—	0.0	—	7.0	—	8.0	—	11.2	—	12.0	—
Maximum	41.9	—	40.5	—	47.0	—	41.1	—	33.4	—	43.8	—

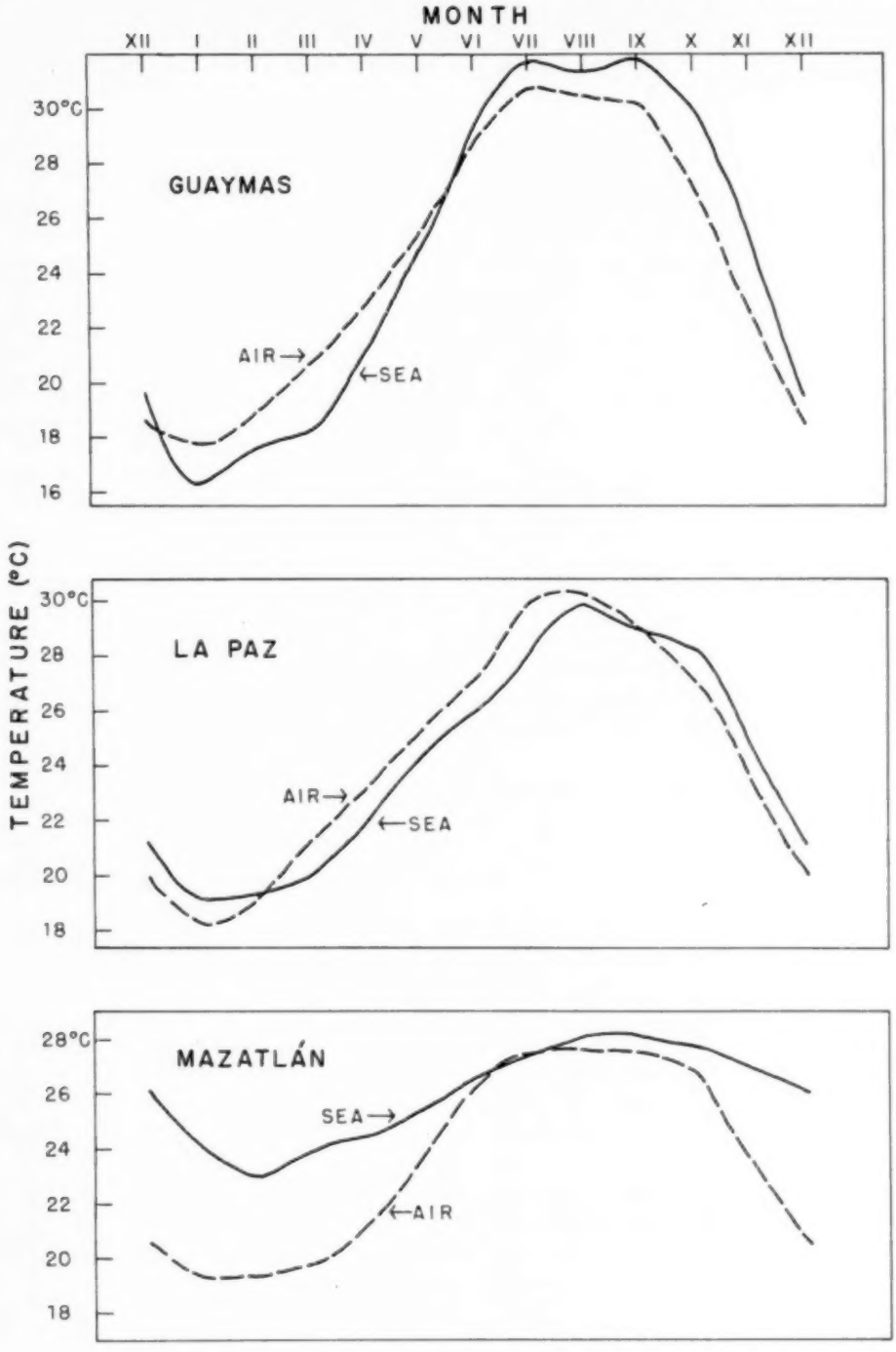

FIG. 5. Air and sea surface temperatures in Guaymas, La Paz, and Mazatlán.

the dry steppe type, and in southern Sinaloa it is tropical.

The distribution of air temperatures (Fig. 5) shows a temperature minimum in January and February and a maximum in August and September. The annual range in temperatures increases from south to north and is somewhat greater along the coast of Baja California than along Sonora and Sinaloa. The mean annual range at the entrance is around 10°C. and in the northernmost part about 20°C. The extreme annual range (Table 1) is approximately twice the average annual range (Serv. Met. Mex., Boletin Anual). In general the air is warmer than the sea during the first half of the year and cooler during the second, except for Mazatlán, where the air is always cooler than the sea (Fig. 5).

The distribution of winds (Table 2) shows that the monthly average wind velocities are quite low, lying between 1.5 m/sec and 6.1 m/sec. The higher values are found in winter and spring. The direction of winds varies with season and with distance from the entrance. During winter, northerly winds are predominant in the entire Gulf, but in summer the southern half of the Gulf is mostly influenced by southerly winds. In the northern half, southerly winds blow only one or two months of a year.

Winter gales of short duration, locally known as chubascos, are frequent and velocities may occasionally reach 30 m/sec.

Hurricanes are not as rare in the Gulf as is generally believed. Between 1910 and 1930 thirty-nine were registered (Schott, 1935: 280). These hurricanes, known as "El Cordonazo," may enter the Gulf any time between May and November, but are most frequent in September and October (Fig. 6).

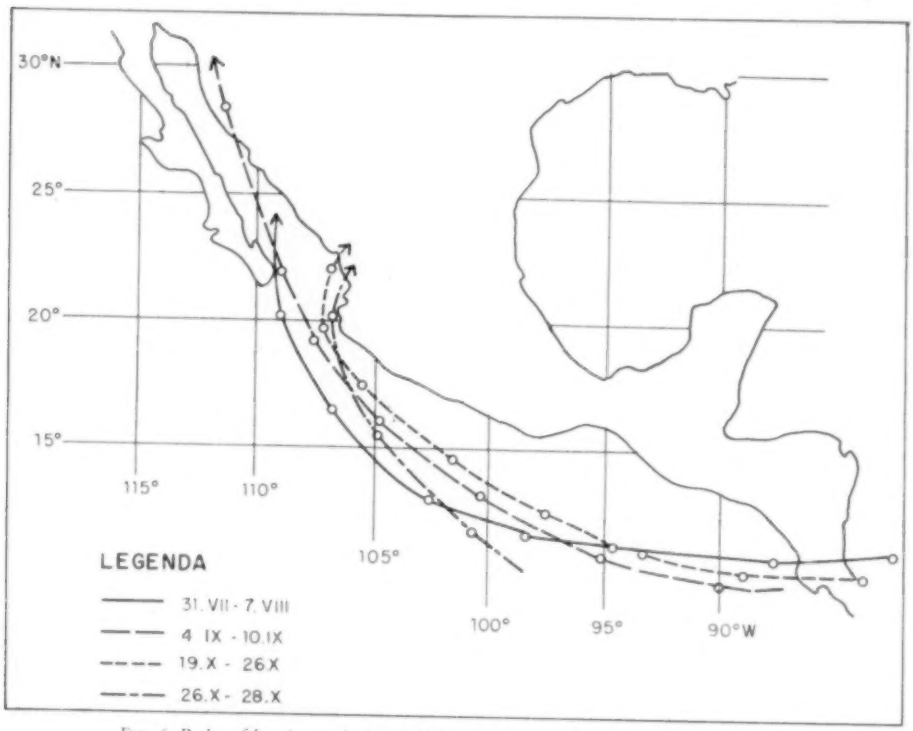

FIG. 6. Paths of hurricanes in 1936. (After Serv. Met. Mex., Boletin Anual, 1936.)

TABLE 2
MEAN MONTHLY WIND VELOCITY IN LA PAZ, GUAYMAS, AND MAZATLÁN
(Serv. Met. Mex., Boletin Anual)

	LA PAZ	GUAYMAS	MAZATLÁN
	m/sec	*m/sec*	*m/sec*
January	2.6	4.8	6.1
February	2.4	4.2	5.9
March	2.2	5.3	5.5
April	2.3	5.1	5.0
May	2.1	4.6	4.8
June	2.4	4.3	4.6
July	2.0	3.5	4.3
August	2.0	3.6	4.9
September	1.5	4.4	5.0
October	1.8	4.8	5.1
November	2.3	4.6	4.1
December	2.3	4.9	5.5
Year	2.2	4.5	5.1

In La Paz winds are northerly from November until March and southerly from April until October.

In Guaymas winds are northerly from August until May and southerly in June and July only.

In Mazatlán winds are northerly from November until April and westerly from May until October.

They originate in the Caribbean Sea or off the coast of Central America and it takes them between five to seven days to reach the Gulf (Serv. Met. Mex., Boletin Anual).

If one compares the distribution of winds and the occurrence of the rainy season with the migrating low pressure system over western Mexico (Fig. 7) it is seen that northerly winds are found with the low pressure to the east, and southerly winds with the low pressure to the northwest. The beginning of the rainy season is connected with the appearance of southerly winds that carry moist air into the Gulf and give rise to uplift rain.

Evaporation is one of the most important factors in the Gulf and is responsible for the high salinity observed in the surface layers. The amount of evaporation has been determined from pan observations at a few shore stations (Serv. Met. Mex., Boletin Anual). These measurements show a main maximum in summer and a main minimum in winter. The amount of annual evaporation varies between 1800 mm. in La Paz and about 3000 mm. in Guaymas (Table 3). The values are consistent from year to year for each station and the deviations from the above values are generally less than 10 per cent (Serv. Met. Mex., Boletin Anual).

Since evaporation from pans is not strictly representative for evaporation from the sea surface, it is of interest to see how the observed evaporation from pans compares to evaporation derived from indirect methods.

The use of the energy budget method is restricted, because the advection term cannot be evaluated.

In the meteorological approach a straight line relationship between the evaporation, E, and the product of wind velocity, W, and vapor pressure difference, Δe, is assumed (Jacobs, 1951); the coeficient of proportionality depends upon the height where the wind velocity and the humidity has been measured, and upon the roughness of the sea surface. In the following the coeficient of proportionality will be taken as 4.26 (Jacobs, 1951) so that

$$E = 4.26\, W\Delta e$$

where E is in mm/month, W in m sec, and Δe is in mb.

A comparison between the pan and computed evaporation for the year 1938 is shown in Table 3, and it is readily seen that notable differences exist. The computed evaporation is less than the observed evaporation (Fig. 8) for La Paz and Mazatlán. In La Paz the maximum evaporation occurs in summer and the minimum in winter; in Mazatlán the observed evaporation shows a winter minimum and a summer maximum, whereas the computed evaporation has a summer minimum and a fall maximum. The summer minimum is due to the low wind velocities observed during this season. Values for Guaymas are not strictly comparable because the pan observations were made on a nearby station farther inland; nevertheless it is interesting to note that there the total annual amount of evaporation is considerably higher than in La Paz or Mazatlán.

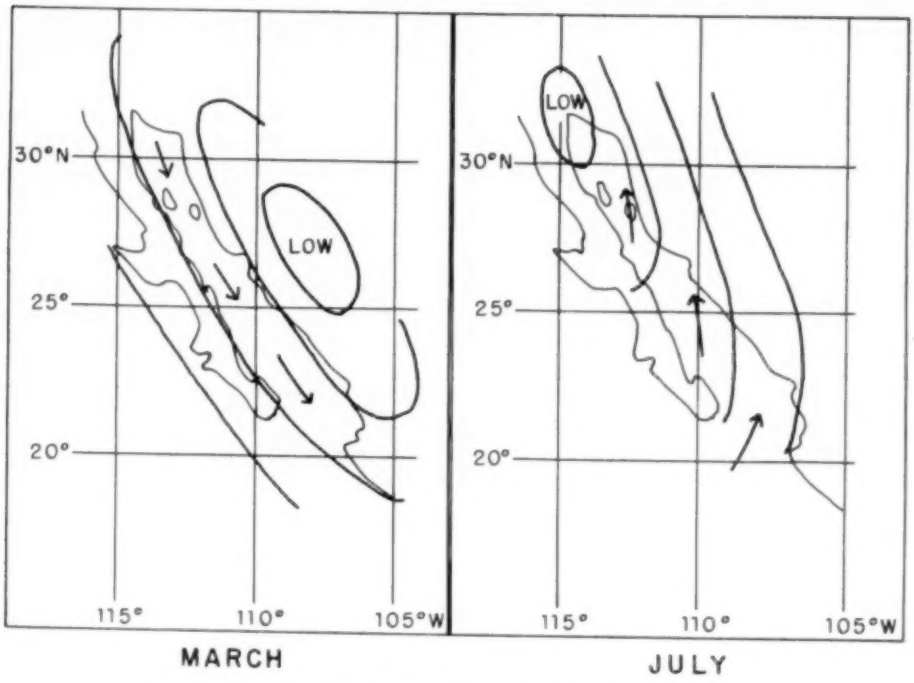

FIG. 7. Position of the low pressure in March and July, and resulting winds.

TABLE 3
MEAN MONTHLY EVAPORATION
E_p = measured from pans, E_c = computed

	LA PAZ (1938)		GUAYMAS (1943)		MAZATLÁN (1938)	
	E_p	E_c	E_p	E_c	E_p	E_c
	mm.	mm.	mm.	mm.	mm.	mm.
January	139	76	139	174	185	172
February	120	41	206	216	213	194
March	129	81	286	269	148	129
April	119	98	351	276	205	133
May	146	127	446	337	210	163
June	166	126	420	299	211	130
July	174	172	294	280	230	123
August	197	156	246	239	289	181
September	150	82	198	266	202	190
October	159	180	162	337	210	245
November	158	98	148	178	162	196
December	154	57	92	288	140	196
Year	1809	1294	2958	3247	2492	2071
(E_c/E_p)year	0.72		(1.10)		0.83	

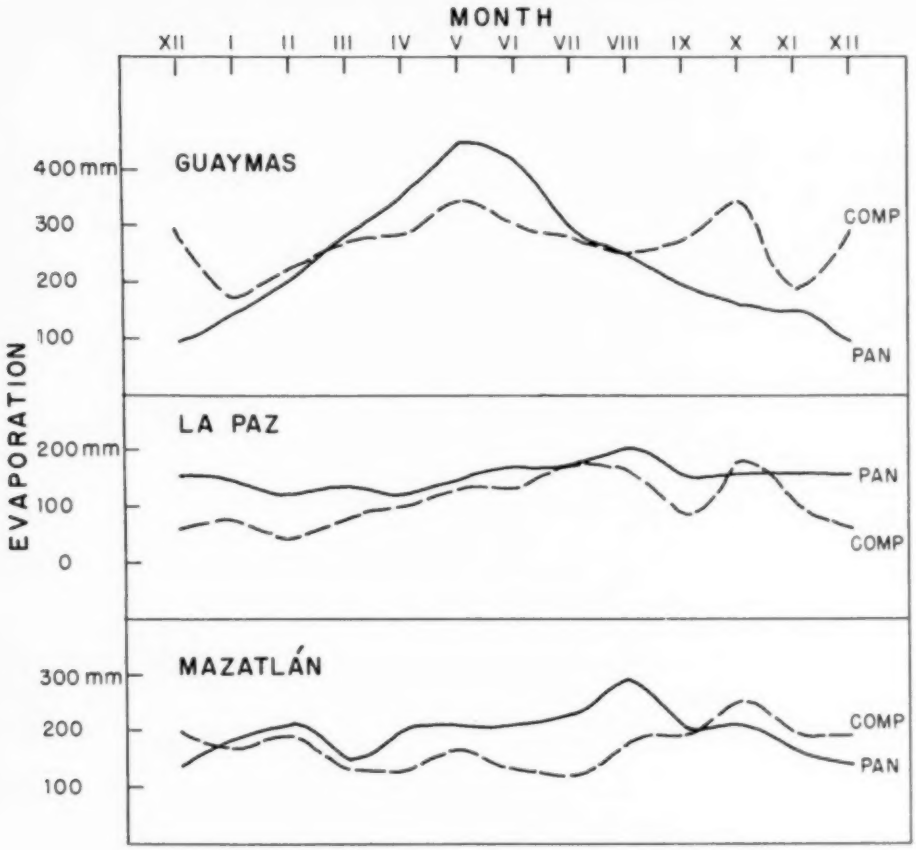

FIG. 8. Computed evaporation (E_c) and pan evaporation (E_p).

The difference, evaporation minus precipitation, has a maximum in early summer, a minimum during the rainy season, and a secondary maximum immediately after the rainy season. Except for Mazatlán during the peak of the rainy season, evaporation exceeds precipitation during all months of the year. The few available data indicate that the mean annual evaporation for the southern half of the Gulf lies between 1500 and 3000 mm. For the entire Gulf, considering the dry northern part, roughly 2500 mm. can be taken as a conservative estimate for the mean yearly evaporation. With this value the rate of evaporation over the entire surface of the Gulf becomes $5.25 \times 10^{11} m^3$/year or $1.7 \times 10^4 m^3$/sec.

GENERAL CIRCULATION

The bulk of water in and near the Gulf of California is the same as in the equatorial Pacific, slightly modified at the surface by extensive evaporation and by the admixture with water brought south by the California Current. The influence of the latter is restricted to the vicinity of Cabo San Lucas.

The great similarity between the Gulf and Pacific Equatorial water, below the thermocline, is illustrated by the close agreement

between the temperature-salinity relationships for either water mass (Fig. 9). Points for the Gulf were obtained from the "E. W. Scripps" expedition in 1939 (Sverdrup and staff, 1943). The solid curves represent the limits for typical Gulf water, the dashed curves show the limits for the equatorial Pacific (Sverdrup *et al.*, 1942: 741).

It is seen that a nearly straight line relationship exists between the points 16°C., 35.2‰ and 9°C., 34.6‰. The salinity minimum lies in both cases between 34.5 and 34.6‰ and has a corresponding temperature of between 5°C. and 7°C.

The circulation in the Gulf is rather complicated and not fully understood. In winter (Fig. 10) outflow takes place at the surface and inflow at greater depths, in summer (Fig. 11) the situation is reversed. Thorade (1909) mentioned one case of oppositely running currents at the surface and at 40 m. near the coast of central Baja California.

In the northern part of the Gulf cooling of high saline water in winter leads to the formation of a bottom water mass (Sverdrup, 1941), which is characterized by a temperature above 10°C. and a salinity above 34.9‰ and a relatively high oxygen content. This water fills the isolated basins of the northern shelf and moves southward along the coast of Baja California (Fig. 19).

Tidal currents are strong in the northern third of the Gulf and may obtain velocities of several knots in the narrows between the islands and near the mouth of Rio Colorado.

The exchange between the Gulf and the Pacific Ocean cannot be calculated accurately from the available data. It is, however, possible to get a rough estimate of the exchange of water and salt across latitude 23°N assuming conservation of these properties. If E denotes the rate of evaporation and if S_i, S_0 and Q_i, Q_0 represent the salinity and amount of the in- and outflowing water, respectively, the following equations hold (Sverdrup *et al.*, 1942: 148)

$$Q_i = \frac{S_0}{S_0 - S_i} E \qquad Q_0 = \frac{S_i}{S_0 - S_i} E.$$

Taking E as 1.7×10^4 m³/sec (see above), S_i as 34.6‰ and S_0 as 35.1‰ one gets:

$$Q_i = 1.19 \times 10^6 \text{ (m}^3\text{/sec)}$$
$$Q_0 = 1.17 \times 10^6 \text{ (m}^3\text{/sec).}$$

It is seen that evaporation plays only a negligible part in the general circulation of the Gulf, and that inflow very nearly balances outflow. If one assumes that the outflowing

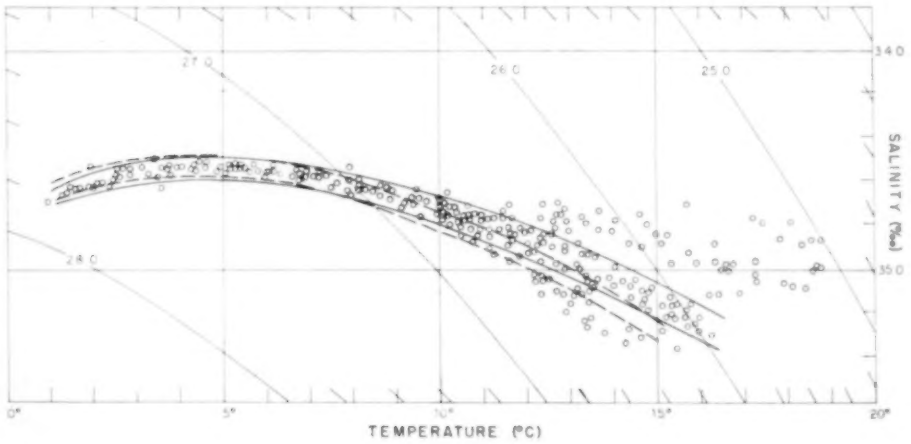

FIG. 9. Temperature-salinity diagram for the Gulf (solid lines) and for the equatorial Pacific (dashed lines).

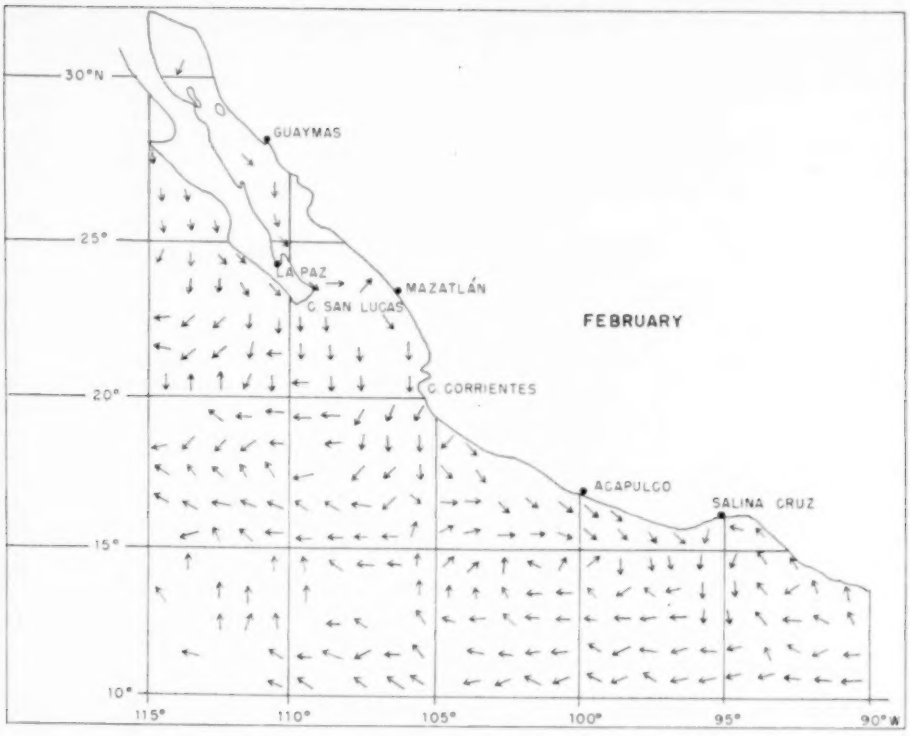

FIG. 10. Surface currents in February. (After U. S. Hydrog. Off., 1947.)

water extends over a depth range of 50 m. and inflowing over 1500 m., across latitude 23°N, the velocity of the outflowing water is 7 cm/sec and of the inflowing water 0.3 cm/sec. This calculation holds only for winter, when northerly winds are responsible for outflow at the surface.

The influence of the Gulf of California upon the adjacent Pacific Ocean is small (Sverdrup *et al.*, 1942: 732) and varies with season. The influence is greatest in winter when strong northerly winds drive the surface layers out of the Gulf and least in summer when southerly winds drive oceanic water into the Gulf. The exact distance seaward from the entrance of the Gulf that Gulf water can be detected (by its higher salinity) is not known.

The circulation in the vicinity of the Gulf of California is affected by the water carried south by the California Current and by the water found off Mexico and Central America. The former is characterized by a low temperature, a low salinity, and a rather high oxygen content, whereas the latter has a very high temperature at the surface and a very low oxygen content below the thermocline (Sverdrup *et al.*, 1942: 730). Between both lies a transition region which, 500 miles to the west, is found approximately between latitudes 17°N and 20°N (Wooster and Cromwell, verbal communication).

In February (Fig. 10) the coastal surface circulation (U. S. Hydrog. Off., 1947) is characterized by southward currents north of about latitude 20°N and by westward flowing currents south of this latitude. An interesting feature is a large gyre off the southern coast of Mexico which is maintained by strong

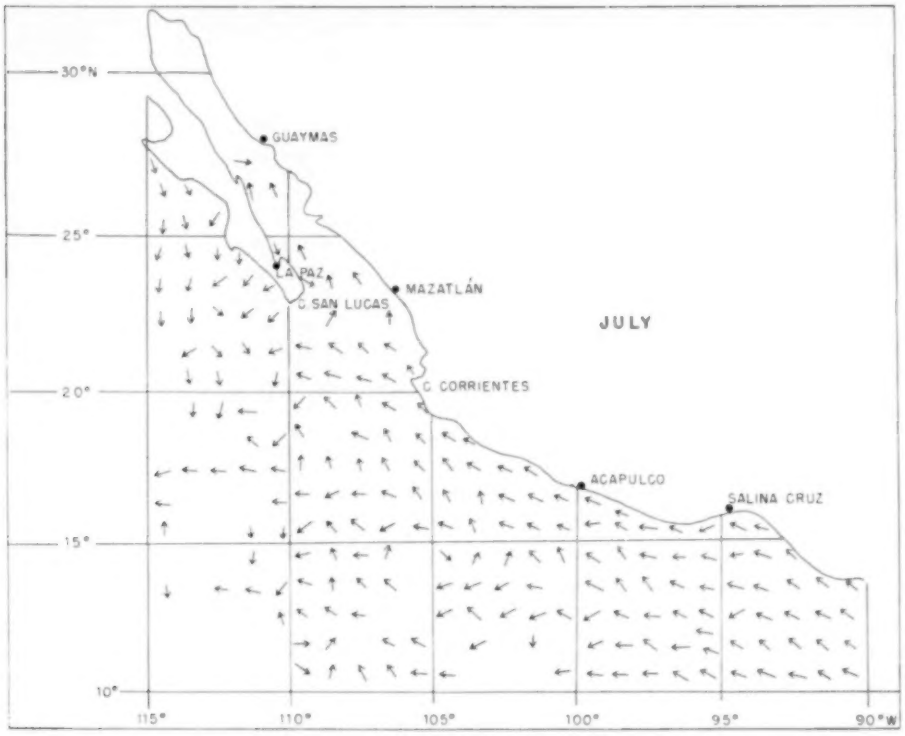

FIG. 11. Surface currents in July. (After U. S. Hydrog. Off., 1947.)

northerly winds blowing into the Gulf of Tehuantepec. This gyre is strictly a winter phenomenon and ceases as soon as the winds in the Gulf of Tehuantepec change their direction.

In July (Fig. 11) a current flows north along the coast of Mexico and enters the Gulf of California. The entire current pattern east of 110°W is characterized by a slowly west to northwest moving water mass. West of this longitude the current is toward the south north of latitude 20°N and toward the west south of this latitude.

The monthly average speeds of these currents are low and lie almost entirely within 5 cm/sec and 20 cm/sec.

FRONTS IN THE VICINITY OF THE GULF

In the following the term "front" will be used as suggested by Cromwell and Reid (1956), i.e., as a narrow band along the sea surface across which the density changes abruptly. The terms "temperature front" and "salinity front" will be used to describe the density front, since it is only from temperature and salinity measurements that the density can be adequately determined. The definite character of a front can only be established if continuous temperature and salinity records are available. Unfortunately there are no continuous records of salinity, for which reason a description of the fronts in the vicinity of the Gulf must be based on closely paced stations rather than upon continuous records.

Two regions of rapid temperature and salinity transition have been found to exist in the Gulf Entrance, one off Cabo San Lucas and one off Cabo Corrientes (Fig. 12). The San

Lucas transition represents a very sharp boundary between warm and high-saline Gulf water, and cool, low-saline water from the California region. It was first described by Thorade (1909), who pointed out that the intensity of the front is seasonal in character and that the maximum intensity occurs in late spring when the temperature differences between the Gulf and California Current water are greatest.

The San Lucas front is illustrated in Figure 13 (unpublished data). It is seen that the front is marked by a narrow band across which the temperature decreases from 21° to 18°C. and the salinity from 34.6 to 34.1‰.

It is possible that when the more saline Gulf water is cooled rapidly some sinking of this water takes place at the front, but this feature has not been investigated. The temperature structure below the San Lucas front is shown in Figure 14. The bathythermograph section from Cabo Corrientes to Cabo San Lucas was prepared from hourly temperature observations made aboard the U. S. vessel "Golden Bear" and led to the discovery of another front in the vicinity of Cabo Corrientes. It is seen that the temperature differences across the front increase with increasing depth. The increase could be explained as the result of decreased mixing at greater depth, but the feature needs further investigation.

Since the winds were northerly in April, 1949, when the "Golden Bear" crossed the Gulf Entrance it can be assumed that an already warmed water mass was driven out of the Gulf and pushed the cooler water north

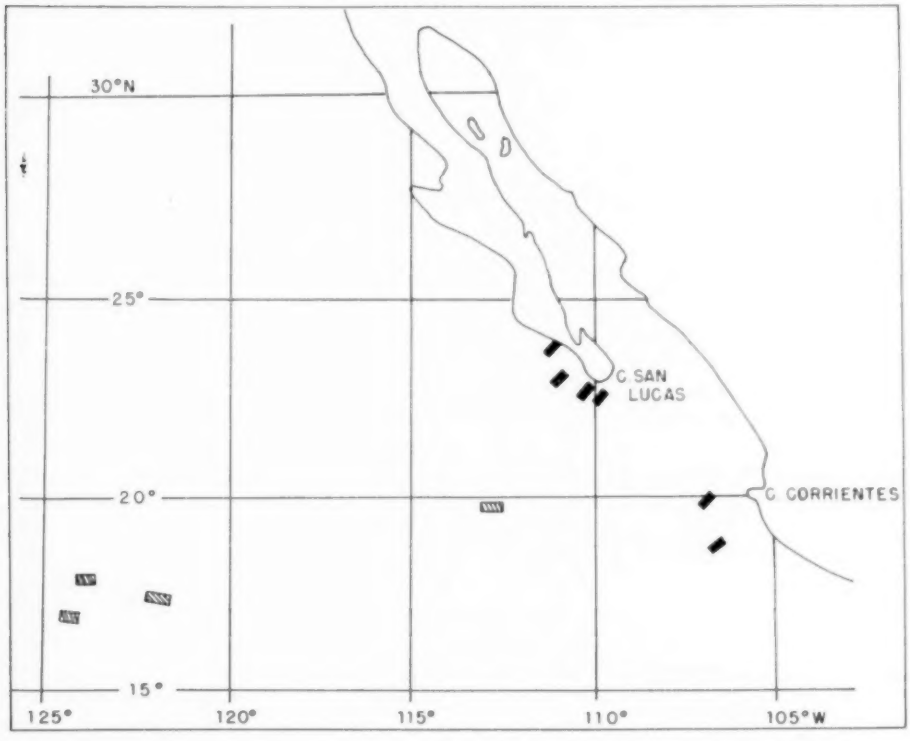

FIG. 12. Observed fronts (solid black) and transition regions (shaded) near the Gulf of California.

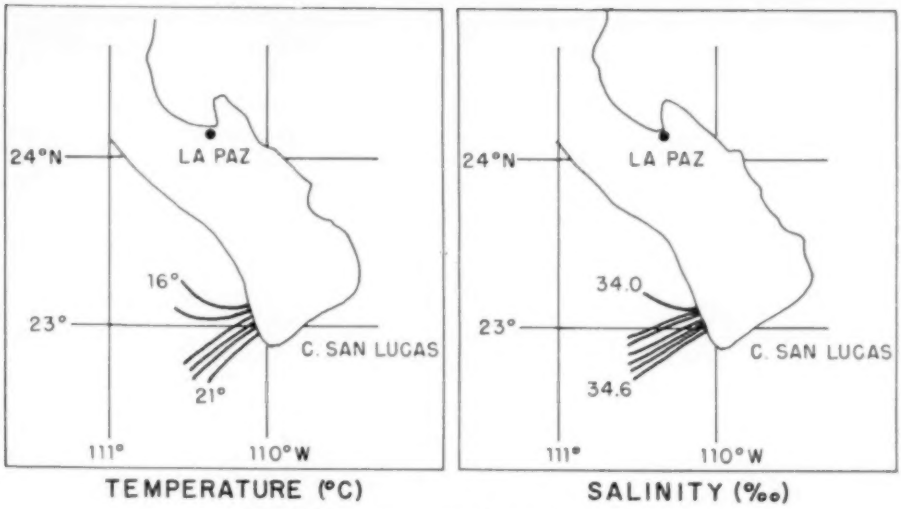

FIG. 13. Surface appearance of the San Lucas front.

of Cabo San Lucas and south of Cabo Corrientes aside, thus giving rise to the fronts observed.

UPWELLING

Upwelling in the Gulf can be expected along the east coast with northerly winds and along the west coast with southerly winds. So far only upwelling along the east coast has been investigated (Allen, 1937).

The upwelled water is characterized by a low temperature and a low salinity when compared to the temperature and salinity of the surroundings. The surface oxygen content of the water is not necessarily a good indicator of upwelling, since it is strongly influenced by phytoplankton productivity, and by exchange with the atmosphere.

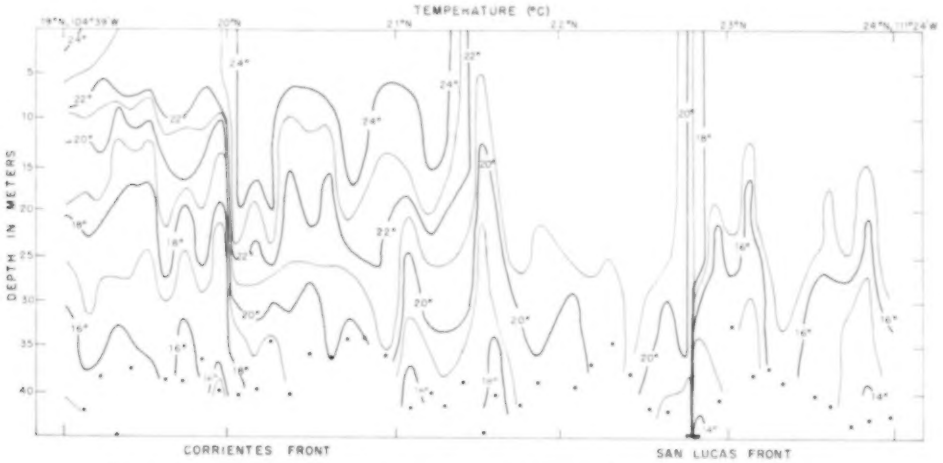

FIG. 14. Bathythermograph section from Cabo Corrientes to Cabo San Lucas, April, 1949.

Upwelling is not uniformly distributed along the east coast with northerly winds but seems rather to be confined to certain places. Such places are in the lee of Isla Tiburón, in Bahia Guaymas, in Bahia Yavaros and in the vicinity of Topolobampo (Allen, 1937). It is interesting to note that all these places are in the lee of islands or headlands, which suggests that upwelling is largely controlled by the irregularities of the coast line as well as by the winds.

Upwelling is important in the Gulf as a means of replenishing the depleted surface layers with plant nutrients from below. There are, unfortunately, no data on the concentration of plant nutrients available for the regions where upwelling occurs, and it is for the time being not possible to investigate the biological role of upwelling in a quantitative manner. The high concentration of phytoplankton in the upwelling areas in spring (Allen, 1937) is indicative, however, of a sufficient concentration in plant nutrients to support the large standing crop.

It should be pointed out that upwelling is not the only process to fertilize the surface layers with plant nutrients. Increased wind mixing and winter convection may be of equal importance. The latter process is effective in the northernmost part of the Gulf (Sverdrup, 1941) whereas the former is beneficial everywhere.

SEASONAL VARIATION OF TEMPERATURE AND SALINITY IN THE GULF

Information on the monthly variation of temperature and salinity at the sea surface in the Gulf is very scanty.

The first attempt to draw charts of monthly average sea surface temperatures was made by Thorade (1909). He collected data from ships' observations for many years and averaged them. These pre-World War I charts are still the only ones in existence (Fig. 3). Since the Second World War the U. S. Coast and Geodetic Survey has published sea surface temperatures from a few shore stations in the Gulf. These are given in Table 4. It is seen that the minimum temperatures occur in January and February and the maximum temperatures in August and September. The mean annual range lies between 23°C. and 28°C. in Mazatlán and between 16°C. and 32°C. in Guaymas. In the northern half of the Gulf the mean monthly temperatures are not known. The minimum in the northernmost part seems to be above 10°C. since this is the temperature of the bottom water found there (Sverdrup, 1941).

TABLE 4
MONTHLY VARIATION OF SEA WATER TEMPERATURE AND SALINITY FOR LA PAZ, GUAYMAS, AND MAZATLÁN (USCGS 1951, Schott, 1935)

	LA PAZ		GUAYMAS		MAZATLÁN	
	t°C.	S‰	t°C.	S‰	t°C.	S‰
January	19.1	35.5	16.3	36.2	24.0	34.8
February	19.3	35.8	17.6	36.0	23.0	34.9
March	20.0	36.4	18.2	35.8	24.0	35.0
April	22.0	36.6	21.0	36.2	24.5	35.1
May	24.4	36.6	24.8	36.4	25.5	35.5
June	26.0	36.4	29.3	37.0	26.7	35.8
July	28.2	36.6	31.7	37.1	27.5	34.8
August	29.8	36.2	31.4	36.3	28.2	34.6
September	29.0	36.2	31.9	36.3	28.0	32.8
October	28.3	36.2	30.0	36.7	27.8	34.5
November	24.7	35.9	25.4	36.2	26.9	35.1
December	21.2	35.7	19.6	36.2	26.1	35.0
Year	24.3	36.2	24.8	36.3	26.0	34.9
Minimum	17.8	34.1	11.0	31.4	—	11.1
Maximum	33.3	40.4	36.2	41.0	—	36.7

The mean annual surface temperature is quite high in the Gulf and lies around 24°C. (Table 4). In Mazatlán the mean annual temperature is very high (26.0) and the surface water there is probably of advective origin, because it is always warmer than the air above it (Fig. 5).

Mean monthly salinities (USCGS 1951) are listed in Table 4. The salinity (Fig. 15) has two maxima and two minima. The first maximum is found around June and is the result of excessive evaporation. With the coming of the rainy season the salinity of the surface water falls and reaches a minimum at the peak of the rainy season. In October increasing winds and rapidly decreasing air temperatures and the lack of large precipitation give rise to a second peak in net evaporation which is also reflected in the second salinity maximum. After the October maximum the salinity de-

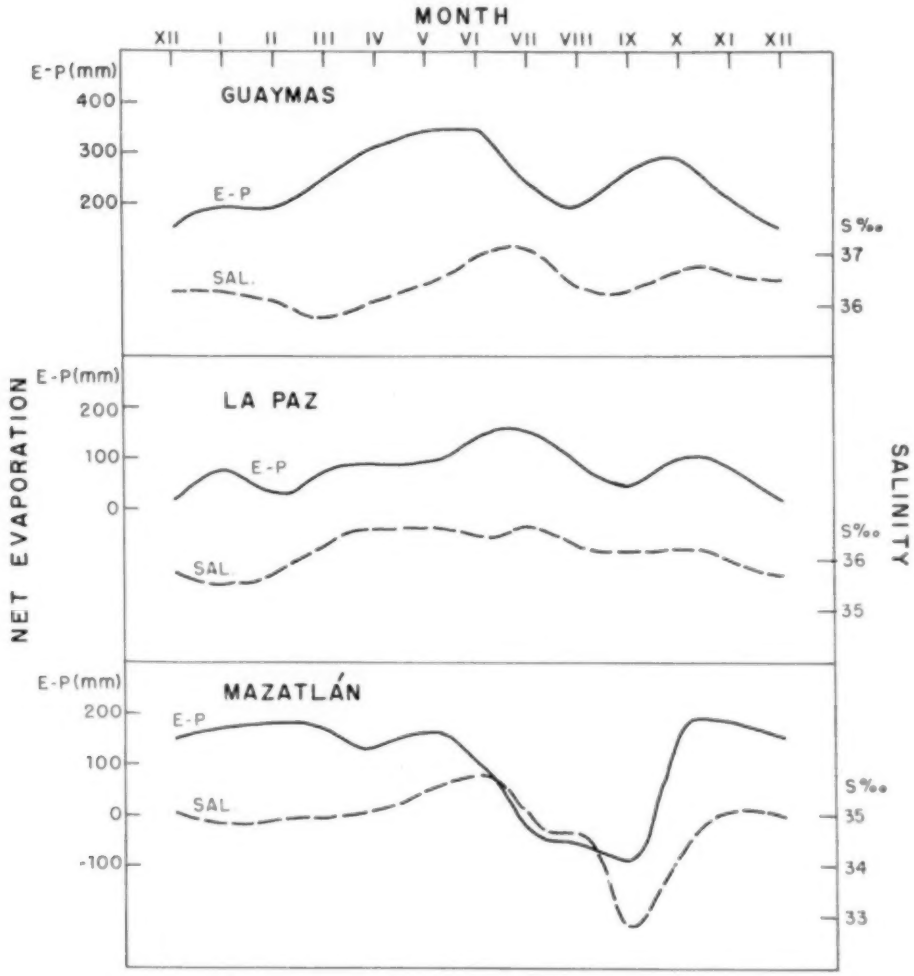

FIG. 15. Net evaporation and salinity for Guaymas, La Paz, and Mazatlán.

creases and reaches a second minimum around December. The salinity ranges between 35.5 and 36.5°/₀₀ in La Paz and between 35.8 and 37.1°/₀₀ in Guaymas. Both places are situated at the head of shallow bays where evaporation is extensive. These values are, therefore, not representative for the open Gulf.

In Mazatlán the salinity varies between 32.8 and 35.8°/₀₀. The very low value found in September (32.8°/₀₀) is possibly caused by extensive runoff from Rio Presidio during the rainy season.

Figure 15 illustrates that there is a very good agreement between net evaporation and salinity. The slight differences seen can be attributed to the different years in which the salinity was observed and for which the net evaporation was computed.

DISTRIBUTION OF PHYSICAL AND CHEMICAL PROPERTIES IN THE GULF

A preliminary discussion of the distribution of temperature, salinity, and oxygen in February and March, 1939, was published by Sverdrup (1941). A short report on the distribution of silicate and phosphate from October to December, 1940, was given by the same author (Sverdrup and staff, 1940). Here only a few conclusions will be drawn from the distribution of these properties. The distribution of phosphate and silicate in the Gulf can be discussed only qualitatively, because the measured data are such that they do not warrant a quantitative discussion.

Vertical Distribution

The Gulf can be divided vertically into a shallow upper layer (20 to 40 m. deep) where the distribution of properties is rather uniform due to wind stirring; a layer between roughly 50 and 150 m., varying with season, where the temperature, salinity and oxygen content decrease rapidly; and a deep layer, between the thermocline and the bottom, where the concentrations remain fairly constant from one season to another.

In the upper layer the concentrations vary considerably with time due to the amount of heating, cooling, stirring, evaporation, precipitation, runoff and various biological activities. Shallow and semi-enclosed bays show greater variations than the open Gulf. The layer of rapid density increase is generally closer to the surface during the warm season than during the cold season, but the available data are too few to give accurate depth ranges. Below the layer of rapid density increase the temperature decreases more or less slowly toward the bottom, but in a few deep basins, below 2000 m., a slight increase is observed due to the adiabatic effect.

The salinity shows a minimum (34.48–34.54°/₀₀) between 600 and 800 m. and increases slightly toward the bottom.

The amount of dissolved oxygen has a very pronounced minimum (less than 0.1 ml/l) between 300 and 700 m. and increases again toward the bottom.

The silicate content increases with depth and equals about 160 μg-at/l in the central part of the Gulf where the bottom deposits are largely diatomaceous oozes.

Horizontal Distribution

The horizontal distributions of temperature, salinity and oxygen in February and March, 1939, are illustrated in Figures 16, 17, 18 and 19.

At the surface (Figs. 16 and 17) the distribution of these properties is very complicated. The high oxygen values (more than 50 per cent supersaturated in places) are probably the result of extensive phytoplankton production. The southern half of the Gulf is slightly undersaturated with respect to oxygen. Upwelling as indicated by a low temperature (and salinity) can be seen to occur in Bahia Guaymas and Topolobampo.

At subsurface depths (Figs. 18 and 19) the two outstanding features are a tongue of warm, high saline and oxygen-rich water moving to the south along the coast of Baja California and a tongue of low saline, cool

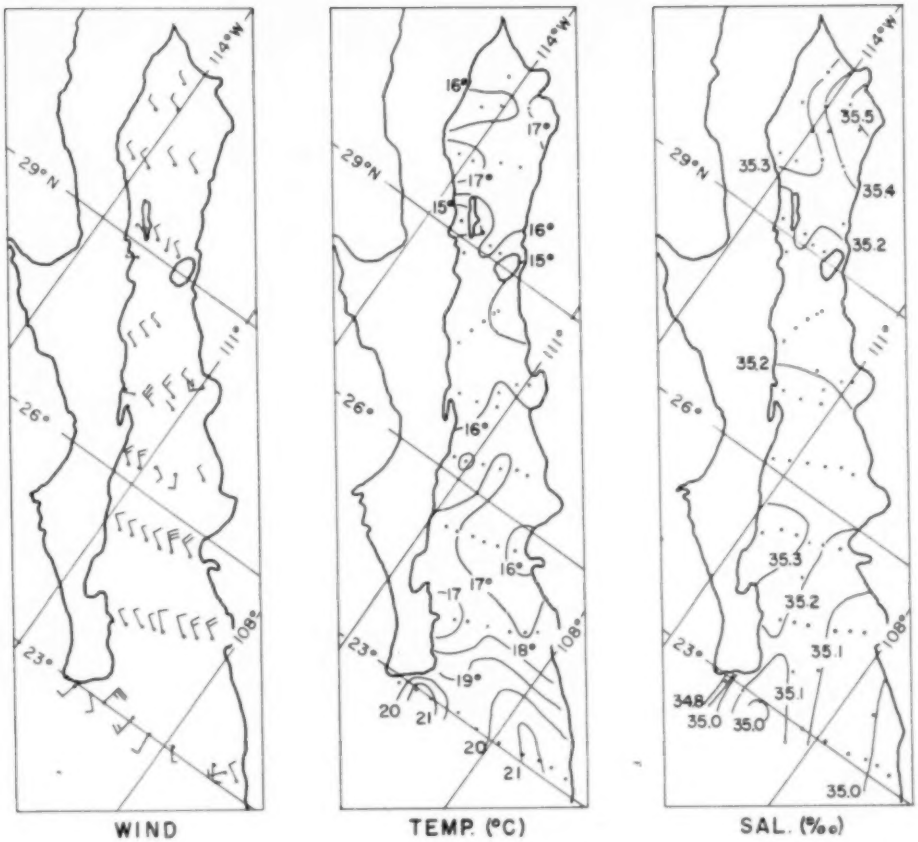

FIG. 16. Distribution of wind temperature and salinity at the sea surface in February and March, 1939.

and oxygen-poor water entering the Gulf from the south. The tongue along Baja California has possibly its origin in the northern part of the Gulf, because it is of nearly the same temperature, salinity and oxygen as the water of the northern area. The inflowing water mass shows the same characteritsics as the equatorial Pacific water (Fig. 9) and represents a compensation flow to replace the water lost by evaporation and wind drift out of the Gulf.

CONCLUSIONS

The Gulf of California remains oceanographically unknown to a great extent. The results that have been presented here are based on meager data and conclusions drawn from such data may have to be modified when more accurate and more complete data are available.

Conditions in the Gulf are dependent upon the conditions in the atmosphere and any changes that take place in the atmosphere will also be reflected in the Gulf. The submarine topography and the orientation of the shoreline also influence the circulation and hence the distribution of properties.

The bulk of the water found in the Gulf shows properties very similar to the Pacific Equatorial water mass. This water mass upon entering the Gulf is modified at the surface by extensive evaporation which increases its

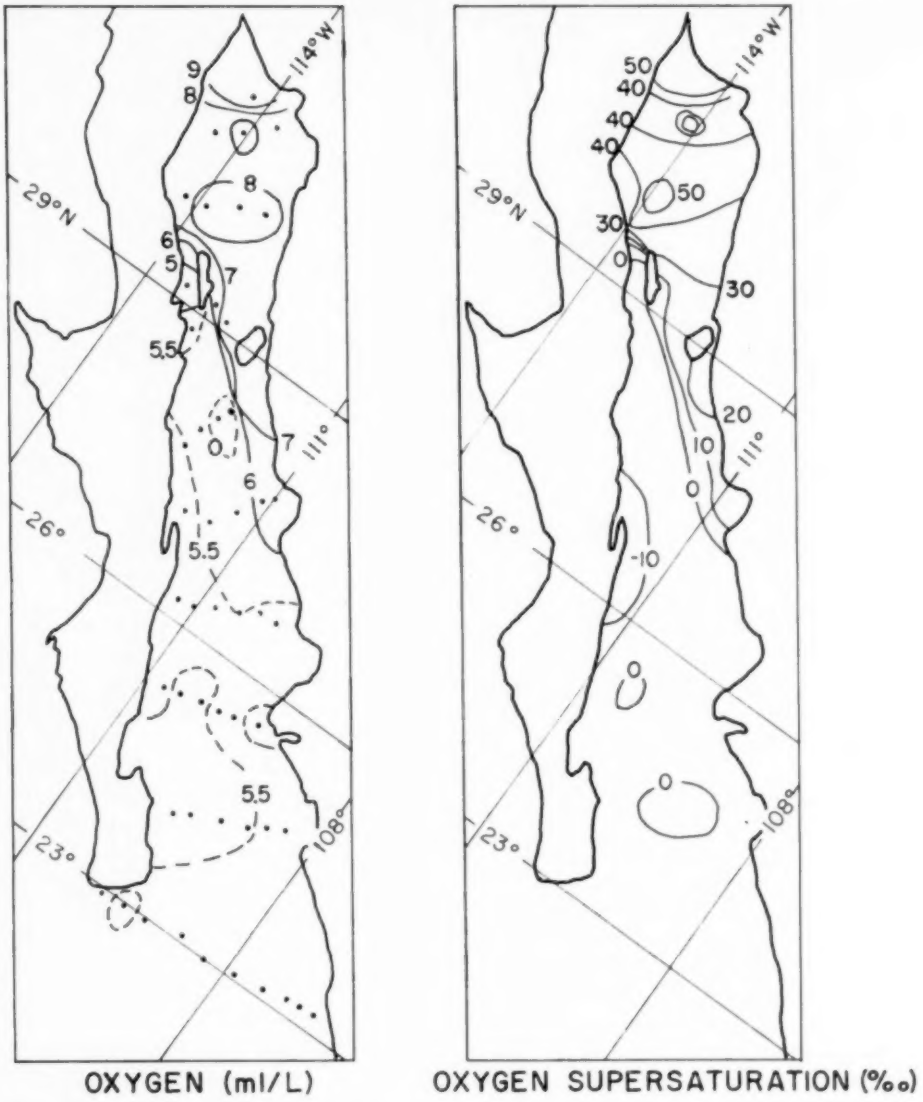

FIG. 17. Distribution of oxygen and oxygen saturation anomaly at the sea surface, in February and March, 1939.

salinity. The effect of evaporation increases as one proceeds toward the northwest.

The circulation in the surface layers is predominantly wind driven. Since the winds transport water of different origin towards the entrance of the Gulf, it is a transition region marked by the existence of fronts of which the San Lucas front is the best developed and best known.

In the Gulf, as elsewhere, upwelling, sink-

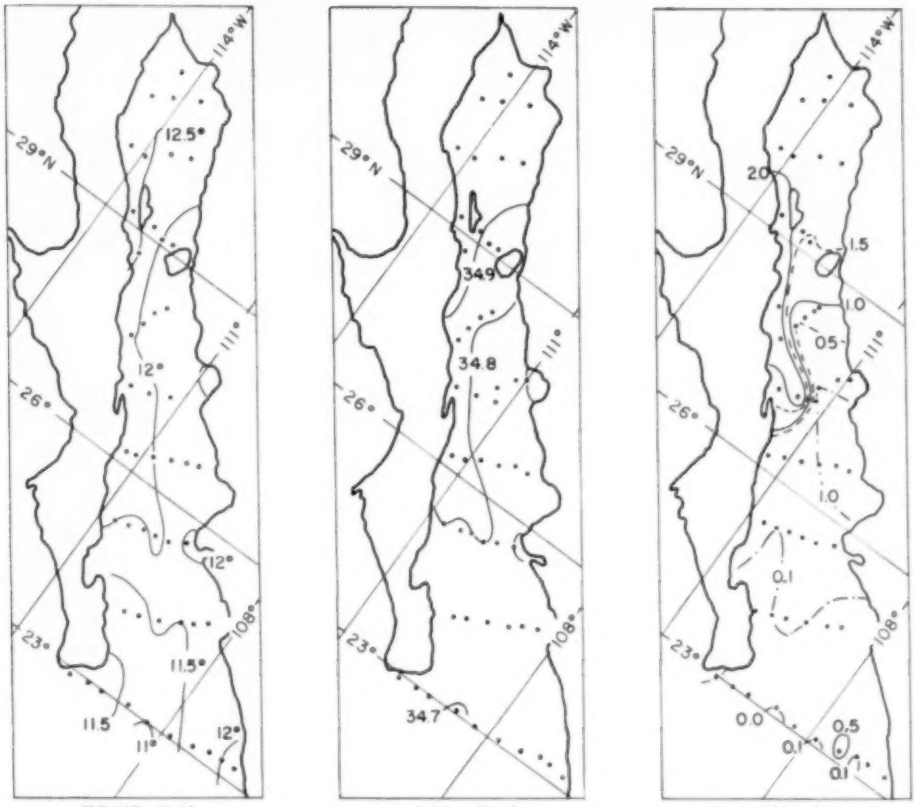

FIG. 18. Distribution of temperature, salinity, and oxygen at 200 m., in February and March, 1939.

ing, and convective overturn play important parts in determining the fertility of any given place. Convection is especially conspicuous north of Isla Tiburón and is responsible for the different hydrographic conditions there. Upwelling is largely found in the lee of headlands and islands, along the eastern coast with northerly winds, and along the western coast with southerly winds. Away from the shores the Gulf is fertile only in spring after considerable winter mixing has brought an adequate supply of phosphates and silicates to the surface. During the rest of the year the surface waters are relatively barren.

The field for investigations in the Gulf is nearly unlimited and it is the hope of the author that in the future increasing efforts will be directed towards the scientific exploration of one of the most fascinating seas in the Pacific, the Gulf of California.

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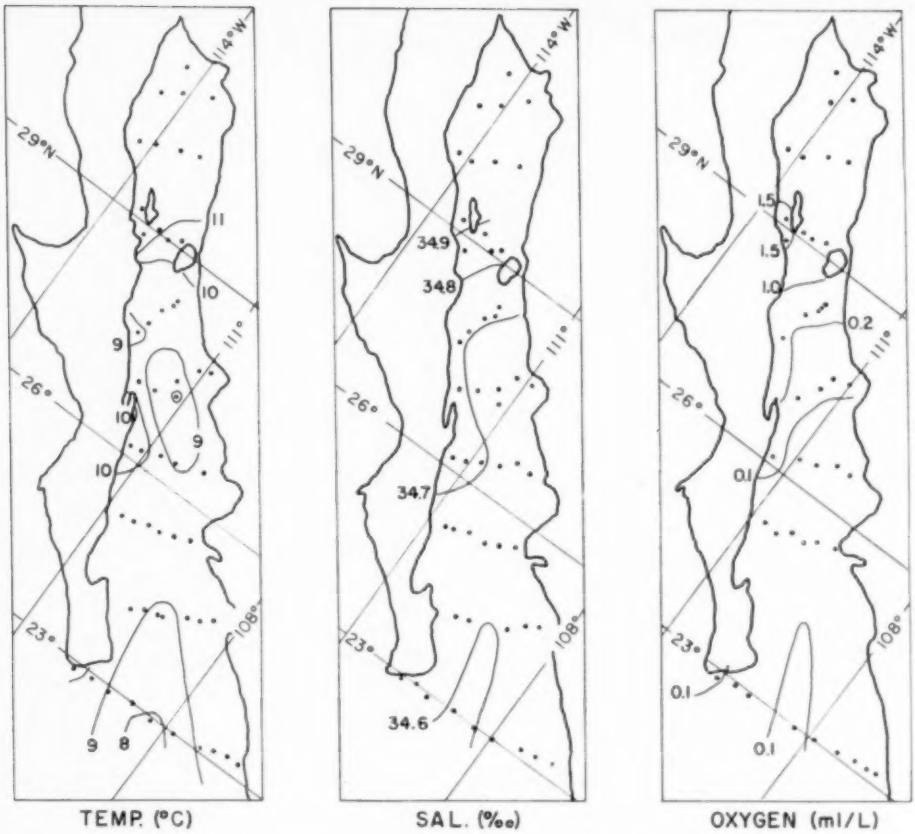

FIG. 19. Distribution of temperature, salinity, and oxygen at 400 m., in February and March, 1939.

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A Closing, High-speed Plankton Catcher for Use in Vertical and Horizontal Towing

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A feature common to conventional conical nets is the speed at which they may be towed —one to two or three knots (1 kt. equals 1.85 km./hr.)—which is necessary to safe working of the gear and an undamaged condition of the catch. Increasing the speed of towing is believed to set up a zone of pressure which advances before the mouth of the net, possibly warning or otherwise causing animals to avoid capture.

Modifications in attempts to improve the efficiency of this basic type of net, include methods of opening and closing nets under water (Kemp, Hardy and Mackintosh, 1929; Marr, 1938; Barnes, 1953; Currie and Foxton, 1957); alteration of its shape, as in the Hensen and Apstein nets (Sverdrup, Johnson and Fleming, 1942), and as made by Sheard (1941), and Barnes (1953); addition of flow meters to determine the volume of water filtered (Harvey, 1934; Clarke and Bumpus, 1940; Arnold, 1952; Currie and Foxton, 1957); and means of taking series of discrete samples (Hart, 1935; Motoda, 1952).

A different approach involves the type of sampler which can be towed horizontally at higher speeds. The mouth in this type usually precedes the towing point (unlike conical nets) so that the sample is collected from undisturbed water; when combined with high speed through the water, this contributes towards collecting a wide range of organisms.

In general, high-speed catchers incorporate a type of conical net, either in a rigid frame (Cassie, 1956), or in a rigid (metal) container (Arnold, 1952; Gehringer, 1952). Usually the area of the mouth is much restricted relative to the area available to filtering the water, but in the Gulf Sampler III (Gehringer, 1952) the diameter of the mouth (16 inches) is almost that of the contained net. Flow meters may be incorporated as in the tail of the Scripps High Speed Sampler (together with a depth recorder); in the Gulf Sampler IA (Arnold, 1952); and in mouth and tail of the Gulf Sampler III (Gehringer, 1952). To the best of our knowledge, no high-speed sampler can be closed when towing is completed.

The Continuous Plankton Recorder (Hardy, 1935) operates on the principle of a continually renewed filtering area, and, although it is a high-speed sampler, is in a different category from those already discussed.

Less attention has been paid to more rapid sampling by vertical tows. In one method (Hart, 1935) flights of small, conical nets are evenly spaced on a wire and are towed over a vertical distance equivalent to the spacing; they are then closed and hauled in. Samples are thus collected simultaneously from several levels. Motoda (1952) incorporates a series of collecting buckets in a frame; unused buckets successively lock on to the cod end of the net during a step-by-step rotation of the frame. Each bucket collects material only over a particular range of depth. None of this style of nets is towed faster than about one metre per second (two knots).

Nets for vertical towing are usually constructed somewhat differently from those for horizontal or oblique tows (Kemp, Hardy, and Mackintosh, 1929). To convert from the one use to the other may be impracticable,

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thus making various sorts of nets almost obligatory. Material thus collected could be compared only with difficulty (e.g., see Winsor and Walford, 1936; Winsor and Clarke, 1940; Barnes and Marshall, 1951). More important, perhaps, is the limitation a multiplicity of gear imposes on assessment of relative efficiencies of vertical and horizontal tows as methods of quantitatively sampling a water column.

The following account is of a plankton catcher designed for both vertical and horizontal sampling, and requiring a minimum of conversion from the rigging for one type of tow to that for the other. Its rigid outer casing is of fibreglass; it has a comparatively wide mouth, contains a conical net of stainless steel, and has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. A valve, which can be closed by a messenger, stops the flow of water into the net, and there is a depth-flow meter in the tail. The diameters of mouth and valve differ, and it is the narrower aperture of the valve that controls the flow into the catcher. It accepts 89 per cent of a column of water, of an equivalent area of cross section, at speeds between 3 and 10 kt. The result encourages us to publish details of the catcher and its performance. The principles of its construction appear sound, but some modifications are being considered in plans for a second instrument.

REQUIREMENTS FOR THE CATCHER

The requirements on which the design of the catcher was based are:

1. That collections made may be profitably subjected to quantitative analysis.
2. That speeds of 6 kt. or faster, both vertically and horizontally, may be achieved.
3. That more than one unit may be attached to a single, vertical wire.
4. That no encumbrances precede the mouth during either vertical or horizontal towing.
5. That it be versatile in catching power.

To be a "quantitative" sampler, the mouth must be closable during vertical and horizontal towing. Second, the volume of water passing through the filter must be measured. Third, development of a pressure zone preceding the mouth must be minimised by making flow through and around the catcher of low impedance.

A low resistance to flow inside the catcher, together with a long streamlined body, contributes towards fast stable towing with least drag. During vertical towing the unit is attached by its side to a weighted wire, and its ability to tow in a stable manner is relied on to reduce the angle at which it hangs (on the vertical wire). Excessive drag would act to increase the angle. The inherent stability also ensures steady true towing at the higher speeds in a horizontal direction.

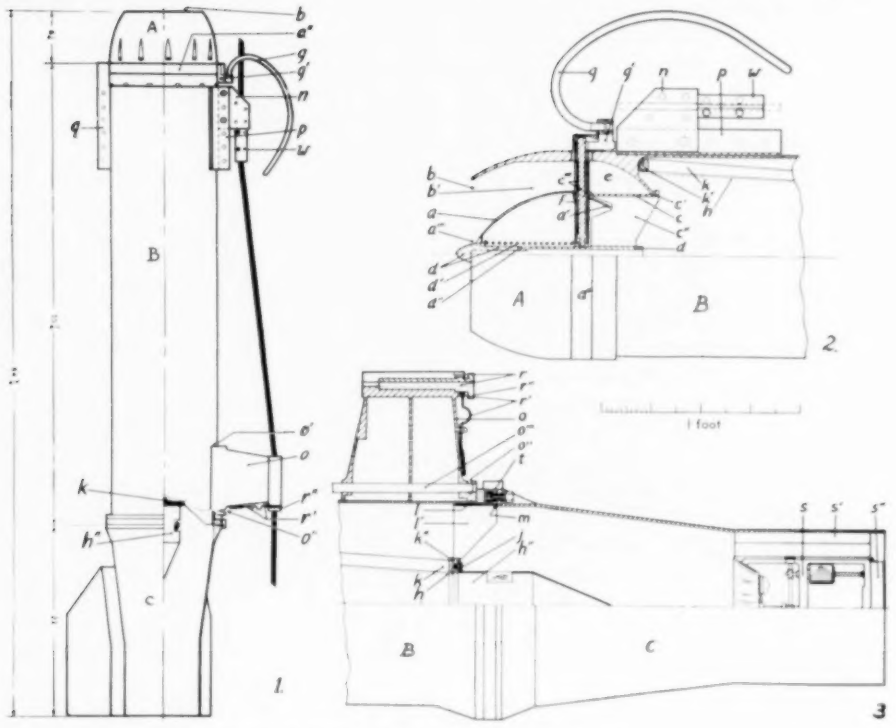
In horizontal tows hauling from a point behind the mouth eliminates bridles, and other attachments, preceding the mouth. The advance of such attachments possibly warns or scares at least the more agile zooplankton. In vertical tows, the wire is to one side of the mouth. It may possibly become a relatively constant feature and therefore not be so disturbing to organisms. The mouth remains otherwise unobstructed.

Fast towing, both vertically and horizontally, and the wide unobstructed mouth are aimed at providing collections which are widely representative of the organisms encountered in a column of water.

DESIGN AND CONSTRUCTION

In Figures 1, 2, and 3 the construction and relationships of parts of the catcher are shown; Figure 4 is a photograph of the dismantled catcher, and Table 1 is a schedule of parts.

The outer shell is rigid, 7 feet long, and can be dismantled into three major sections, nose-, body-, and tail-pieces (Figs. 1 and 4, A, B, C). The nose incorporates the opening of the mouth and the closing mechanism, the body contains the conical net, and the tail the depth-flow meter and stabilizing fins. Normally the nose is bolted to the body, but the



FIGS. 1–3. (1) General diagram of catcher, rigged as for vertical towing.
(2) Nosepiece, mouth chamber, and valve chamber showing the relationships of the parts to each other, to the forward end of the body and the net. Note that the valve is closed.
(3) Tailpiece showing the after end of the net, its frame, the depth-flow meter and the vertical-wire bracket.
Note: Figures 2 and 3 are to same scale and are × 2, Figure 1; for legends, see Table 1.

tail is removable and the net then can be freely withdrawn towards the rear.

Nose, body, and tail (including the fins) are manufactured from Crystic 191, an epoxy resin, with fibreglass reinforcement. These materials have important advantages. Together, they are tough, light in weight (specific gravity 1.3 approx.) and non-corrodible in seawater. Absorption of water is very low and they have proven dimensionally stable in the catcher under diverse conditions of towing and handling. They have been subjected to pressure at 1500 m. without any indication of delaminating or pulverizing in spite of small entrapped bubbles of air.

The opening of the mouth is 9 in. in diameter and leads into the mouth chamber (Figs. 1, 2, 4, *b*). Behind, and partly contained by the nosepiece, is a separate valve chamber (2, *e*). Castings forming the mouth and valve chambers are mounted on a cast bronze ring (Figs. 1, 2, 4, *a''*). The internal surfaces of the chambers and ring are continuous, and they curve inwardly towards the rear, where they form a circular opening of 7½ in. diameter. The inner surface of this acts as a bearer to the outer face of the valve (2, 4, *c'*).

The valve (Figs. 2, 4, *c*) is a short, open-ended cylinder, of 7¼ in. internal diameter.

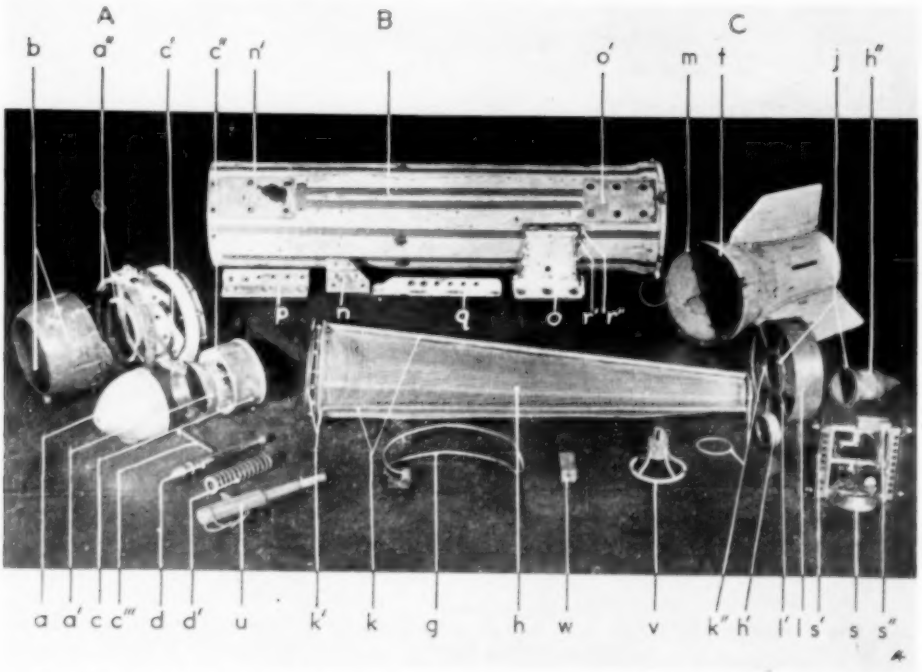


FIG. 4. The parts of the catcher displayed and showing their approximate relationships. For legend, see Table 1.

Radial fins (2, 4, *c''*) attach to its inner surface and to a central, stainless steel, spindle (2, 4, *d*) which protrudes forward from the valve and guides the valve, and around which a groove (2, *d''*) has been turned. When closed, the leading edge of the valve abuts against the trailing edge of a streamlined boss (2, 4, *a*), set in the mouth, and the forward end of the spindle closes a hole of 1 5/16 in. diameter (2, *a'''*) in the front of the boss. A faring (2, 4, *a'*) extends rearward from the boss to improve streamlining. Four holes, 3/16 in. diameter, pierce the front end of the boss. When the unit is raised from the water, air enters by these and enables entrapped water to escape freely.

The valve is opened by pushing the spindle towards the rear with a thruster or loader (4, *u*) through the hole in the boss. This compresses a coiled spring (2, 4, *d'*), fitting round the spindle. The valve is locked open by a spring-loaded, radially mounted, detent pin (2, 4, *c'''*) which clicks home in the groove turned in the spindle. The pin is withdrawn from the detent position when the release arm (1, 2, 4, *g*) is actuated by the weight of a messenger (4, *r*; 6, 7). The spring-loaded spindle is thus released and moves the attached valve rapidly forward, shutting off the flow of water to the net.

The filtering net (Figs. 2, 3, 4, *b*) is of stainless steel mesh; joints are folded, spot welded and then sealed with "Araldite." The ratio of the total area of the filtering holes and the valve (see below) of the catcher is approximately 11 for a net of 40 meshes to the inch and 14 for a net of 10 meshes to the inch. A frame encloses the net. It consists of three tubular brass struts (1, 2, 3, 4, *k*) attached to a forward clamp ring (2, 4, *k'*),

TABLE 1
LIST OF PARTS OF CATCHER, DESIGNATED IN FIGURES 1 TO 4

SECTION	DESIGNATION	PART	FIGURES IN WHICH PART IS PRESENT			
			1	2	3	4
Nosepiece	A		x	x		x
	a	Boss		x		x
	a′	Boss, after faring of		x		x
	a″	Boss, supporting ring (Bronze)	x	x		x
	a‴	Boss, forward hole in		x		
	b	Mouth	x	x		x
	b′	Mouth, chamber		x		
	c	Valve		x		x
	c′	Valve, bearing surface for		x		x
	c″	Valve, radial supporting fins		x		x
	c‴	Valve, detent pin and spring		x		x
	e	Valve, chamber		x		
	d	Spindle to valve		x		x
	d′	Spindle, coiled closing spring		x		x
	d″	Spindle, groove for detent pin		x		
	f	Housing for detent pin and spring		x		
Bodypiece	B		x	x	x	x
	g	Closing mechanism release arm	x	x		x
	g′	Closing mechanism release arm, attachment point	x	x		
	h	Net, (Stainless steel)		x	x	x
	h′	Net, stretcher ring for cod end				x
	h″	Net, plankton bucket	x		x	x
	j	Locking studs for bucket			x	x
	k	Net frame, (struts of)	x	x	x	x
	k′	Net frame, forward clamp rings		x		x
	k″	Net frame, after clamp rings			x	x
	l	Net frame, thrust ring			x	x
	l′	Net frame, radial fins between thrust ring and struts			x	x
	m	Thrust surface of tail			x	x
	—	Towing brackets	x	x	x	x
	n	Towing, vertical, forward	x	x		x
	n′	Towing, vertical, attachment area				x
	o	After, vertical bracket	x		x	x
	o′	After, vertical, attachment area				x
	o″	After remote messenger release point	x		x	
	o‴	After remote messenger release rod			x	
	p	Horizontal towing bracket	x	x		x
	q	Depressor bracket	x			x
	—	After bracket, wire-catch	x		x	x
	r	Wire-catch, slot for wire			x	
	r′	Wire-catch, locking catch and spring	x		x	x
	r″	Wire-catch, rotating central spindle	x		x	x
Tailpiece	C		x		x	x
	s	Depth-flow meter			x	x
	s′	Depth-flow meter, runner mounting			x	x
	s″	Depth-flow meter, revolution counter			x	x
	t	Locking studs of tail			x	x
Miscellaneous	u	Loader				x
	v	Messenger				x
	w	Wire stop	x	x		x

which holds the upstream end of the net to the frame. At the rear the struts attach to a flange (3, 4, *k''*) which fits snugly about the cod end of the net. The cod end, in turn, is forced against the flange by a conically shaped stretcher ring (4, *b'*), fitted internally. Radial fins (3, 4, *l'*) extend outward from the flange to a deep thrust ring (3, 4, *l*) When the frame and net are inserted into the body from the rear, the thrust ring locates the after end (Fig. 3), and the clamp ring locates the forward end (Fig. 2). The forward end of the tail has an internal diameter 3/16 in. less than the after end of the body. When the tail is on, an internal lip is formed (3, 4, *m*) which abuts against the rear edge of the thrust ring, and provides a thrust surface. The assembly serves to push the net from the downflow end into the water entering through the valve. On removing the tail the frame is retained by a spring clip which is attached to the thrust ring, and which engages with the body. The tail is locked onto the body by a simple, external catch after a part turn has been made over locking studs (3, 4, *t*). The plankton bucket (1, 3, 4, *b''*) is removed after releasing a clip and also making a part turn over locking studs (3, 4, *j*). Its rear end is streamlined where it extends back into the tail piece.

The depth-flow meter (Currie and Foxton, 1957) is fastened in the tail on two runners (Figs. 3, 4, *s*, *s'*). It can be slid rearwards, clear of the end of the tail, to facilitate its being handled and read. The impellors turn only with forward motion of the catcher and rotate a drum on which a smoked glass cylinder is slipped. We have modified the meter so that the drum in turn drives a dial-type revolution counter (3, 4, *s''*). A Bourdon pressure unit is attached to a pen and, on reduction of pressure, causes a longitudinal trace to be made on the smoked cylinder. During a vertical tow, this is combined with rotation of the cylinder, when a helical trace results, from which depth and flow can be obtained. In a horizontal tow, the revolution counter gives the number of turns made by the cylinder while the trace on its surface gives the depth to which the catcher was lowered, and at which it was towed. The amount of water which passes through the net during the period of lowering is also indicated.

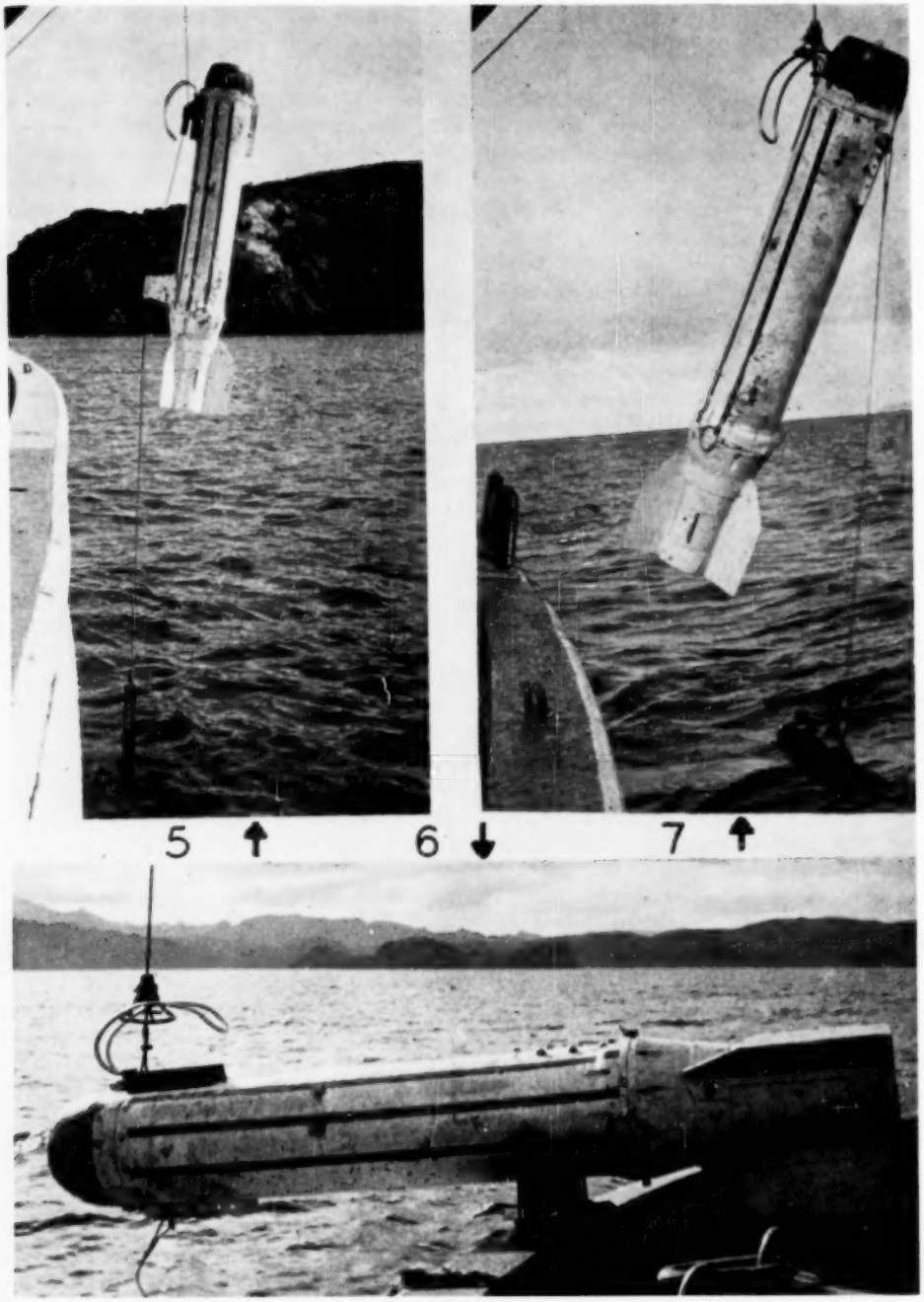
The weight of the catcher is 120 pounds (54.5 kilos) when rigged for horizontal towing, and 130 pounds (59 kilos) for vertical towing. To these must be added, respectively, 45 pounds (20 kilos) for a depressor (Fig. 7), and 45 pounds for a lead sinker (Fig. 5).

TOWING ATTACHMENTS AND RELEASE ARM

Vertical Towing

Vertical towing requires forward and after brackets for attaching the wire to the catcher (Figs. 1, 2, 4, *n*, *n'*, and *o*, *o'*). The catcher is supported by the forward bracket on a stop (1, 2, 4, *w*) on the wire; the after bracket is a spacer. Free rotation about the wire is allowed. The wire is inserted via a slot (3, *r*) into a central rotating portion (1, 3, 4, *r''*), which turns through 180° and is locked in place by a spring clip (1, 3, 4, *r'*). Initially forward and after brackets were similar. Each held the wire about 7 in. off the side of the catcher, but this method introduced many difficulties and had to be abandoned. In the method now employed the after bracket remains, but the forward bracket (a temporary one, see Figs. 1, 2, 4, *n*) offsets the wire by only 3 in. It is inserted in, and attached to, the horizontal towing bracket (1, 2, 4, *p*) which has a **U**-shaped section. Underwater observations indicate that at a vertical towing speed of 2 to 3 kt. the catcher is at an angle of about 5°, but as the speed is increased to 6 kt. the angle progressively decreases until for all practical purposes, the unit tows in a vertical position.

The heavy sinker (45 pounds, Fig. 5) is not necessary when towing vertically, but is essential during rapid lowering to reduce a tendency in the catcher to dive nose first. As the valve is open, the catcher would be fishing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6
7

and the flow-meter registering were this permitted.

To facilitate using flights of catchers on a vertical wire, a mechanism for releasing a messenger from the after end of each catcher was constructed. The impact of the messenger on the release arm set free the lower messenger which, in turn, triggered the closing mechanism of the next catcher down the wire, and so on. Part of the mechanism was in the rear bracket and is shown in Figure 3, *o''*, *o'''*; some of it was also built into the original forward bracket, but this has not been continued in the present one. The assembly has now been dismantled, but there are few difficulties to its reintroduction.

Horizontal Towing

To convert from the rigging for vertical, to that for horizontal tows, takes about five minutes. The wire stop, and the after and forward brackets are removed. The eye of the towrope is inserted into the bracket (Figs. 1, 2, 4, *p*) used for horizontal tows, at a point close behind the attachment of the release arm of the closing mechanism (1, 2, *g'*).

Because the catcher is required to be towed at depth, a 45-pound depressor (as supplied by Scripps Institution of Oceanography) is attached (Fig. 7). It hangs on a free wire from a bracket on the underside of the forward end (1, 4, *q*). It is most efficient, but in rough weather it is difficult to handle, and causes further trouble when it snatches into passing waves. A removable, adjustable, built-in depressor would be desirable in a future model.

The Release Arm (Closing Mechanism)

The same release arm (Figs. 1, 2, 4, *g*; 5, 6, 7), of stainless steel tubing, operates the closing mechanism in vertical and horizontal towing. It is essential that the surface which the messenger strikes is approximately at right angles to the run of the wire. Provision for this is made in the curvature of the arm. The messenger (4, *r*; 6, 7) carries a ring on a frame from its base, so that the two sides of the arm are struck, wherever the wire is located between them.

Features which are novel to the plankton catcher are its fibreglass construction, the sleeve-type valve for stopping the flow of water into the net, and the readiness with which conversion from a catcher for vertical towing to one for horizontal towing is carried out (without alteration of the catching power).

EFFICIENCY TRIALS

Trials to determine the efficiency with which the catcher accepts the water presented to it, and the effects that nets may have, have been carried out. The course and nature of the flow through the mouth and valve are indicated by tests with a two-dimensional model.

Model Tests

The model of the mouth and valve is a full-scale longitudinal, sagittal section, one-half inch thick, which is sandwiched between sheets of "Perspex," screwed to the model and to separating pieces at the sides. A diffuser placed between inlet ports and model ensures that parallel lines of flow are presented to the model. Flow lines were indicated by cotton threads attached to a small metal sledge (made in the form of a box, but open to the flow at the sides) which was manoeuvred about the model with a magnet. The width of the test channel is 18 inches by one-half

FIGS. 5–7. (5) The catcher before lowering for a vertical haul. The lead sinker just clears the surface of the water. (The dark stripes on the body are "Scotchlite" fluorescent tapes which assist during subsurface observations.)

(6) The catcher, rigged for horizontal towing, hanging in the guardrail crotch. The nose-down position, as illustrated, is a steady one when moving between stations. Until the net is withdrawn, however, the nose is kept higher than the tail.

(7) The catcher as recovered from a horizontal tow. It is closed, as shown by the head of the spindle protruding from the mouth; a messenger rests on the release arm of the closing mechanism. The depressor hangs below the catcher.

inch, of which the mouth intercepts 9 in. The remaining 9 in. is divided between the channels lateral to the model. Each of these narrows from 4½ in. to 2½ in.

Figure 8 is a composite drawing and shows the flow lines at an estimated 4 kt. (left half) and 1 to 2 kt. (right half). A positive pressure gradient builds up lateral to the model, as a result of the restriction to flow due to the narrowing of the channels, and is probably responsible for the inwardly sloping flow lines at, and preceding, the leading edge of the mouth. There is a similar, but stronger, inflow towards the hole in the front of the boss. A positive pressure gradient again would seem to be the cause, but arising in the nature of the flow around the boss, and along the channels of mouth and valve chambers. The effects of the gradients become more evident at the faster rate of flow. It is possible that the representation of the flow lines preceding the leading edges of the mouth of the model are not what would obtain in open water with the catcher. However, flow lines into the hole in the boss are distorted by pressure developing as a result of the design of the mouth and valve chambers, and in this case the effect would probably also occur with the catcher. Should either gradient persist during towing, a zone of higher pressure would precede the mouth. This feature is undesirable, although the end result may well be to reduce the actual mouth area to an effective one more nearly equivalent to the area of the orifice controlling the flow into the catcher, namely the valve (see later).

Flow through the mouth and valve chambers (Fig. 8) follows the channels "lateral" to the boss in clean and definite lines. Compression of the lines towards the outer surface of the channel, obvious at the faster rate, suggests that more water flows along this margin. At the higher rate, the lines leave the margin at a position preceding the valve and tend to straighten. The faring at the after end of the boss deflects the flow towards the valve where this occurs. Inside the boss, the main flow forms a distinct pattern near the spindle, but strong turbulence is evident beyond this. The main flow assists effectively in forcing the water from mouth and valve chambers into the valve opening. Even so, and largely because there is a sharp change of direction in flow from valve chamber into the valve, cavitation and turbulence are induced on the inner face of the valve. Therefore the valve may not be accepting water to its full capacity.

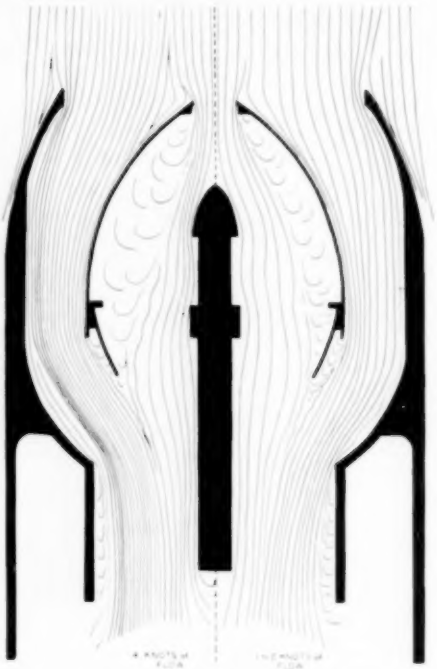

FIG. 8. Composite drawing showing flow lines for estimated speeds of 4 kt. (left half) and 1–2 kt. (right half).

These tests demonstrate that the flow patterns in mouth and valve chambers are satisfactory, evidence which is of value in assessing whether this design is functioning adequately. It is regretted that higher rates of flow were not available for further tests.

Efficiency of the Catcher

Relative efficiencies between the catcher

rigged with no net, with a net of 10 meshes/in., and with a net of 40 meshes/in., are shown in Figures 9 and 10. The catcher with each rig was towed over a straight course of one nautical mile (determined by radar). Each run was timed, and calculated speeds ranged between 3 and 9 knots. The flow meter was read at the beginning and end of each run.

Meter readings were highest when no net was enclosed—about 390 revolutions/mile (Fig. 9). The 10-mesh net caused a reduction to 345 revs./mile (about 11.5 per cent), and the 40-mesh net to 310 revs./mile (about 20.4 per cent). Thus, some restriction to flow is introduced with the nets. That this is due to frictional resistance offered to flow past the strands of the net, and not to insufficient filtering area, is suggested by two sources of evidence. When moderate blooms of diatoms are encountered the 40-mesh net clogs at first only in the lower 12 to 24 in., indicating that filtering is occurring over a relatively small area of the net. More convincing evidence is illustrated by Figure 9, where revolutions per mile of tow are plotted against speed of towing. It is apparent that over the range of speeds utilized there is no reduction in the number of revolutions, for each of the rigs investigated. This is an important point and shows that the quantity of water filtered per unit of distance is constant for each rig, although the volume presented per unit of time increases with the speed. If there were an insufficient area to filter the flow (or if there were other restrictions, the effects of which increased with speed), less water per unit of time would be accepted at the higher speeds and fewer revolutions recorded for a given distance.

An approximate calibration of the meter has been made for several speeds. It was towed mounted in a straight tube, 3 ft. long and 9 in. in diameter (the same diameter as the mouth and tail of the catcher). It is assumed the tube accepts all of the volume of water in a column with a cross-sectional area equal to the tube. The meter recorded

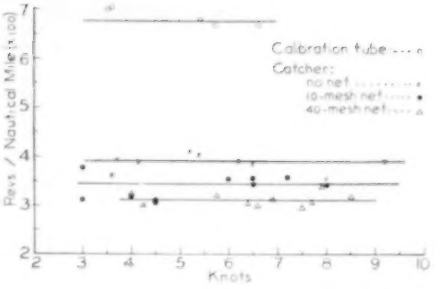

FIG. 9. Revolutions of the depth-flow meter per nautical mile plotted against speed of towing. The uppermost curve is from the readings obtained when towing a straight tube, 9 in. in diameter; the lower three curves result from towing the catcher with no net (upper), with a net of 10 meshes (middle), and a net of 40 meshes/inch (lower).

approximately 675 revolutions per nautical mile. Against this was the recording of 390 revs./nautical mile for the catcher (without a net). This represents an apparent acceptance value for the catcher of only 57.8 per cent (Fig. 10). Such a value suggests a major restriction to flow in the catcher, and it is probable that this is caused by the narrower orifice, namely the valve. This being so, the ideal acceptance would be in the ratio of $\frac{\text{area of valve}}{\text{area of mouth}}$, which is 0.649, i.e., the valve should accept 64.9 per cent of the water presented to the mouth. That the actual acceptance (57.8 per cent), by the valve is lower than its theoretical acceptance (64.9 per cent), indicates other, but less obvious, restrictions to flow. Cavitation on the inner face of the valve, and some details of the construction, are probably factors to be considered.

The volume of water in a column one nautical mile long (1.85 km.), of a diameter of 9 in. (22.9 cm.), is 76.7 m^3. The meter in the calibration tube recorded 675 revolutions for this volume, which is equivalent to 0.114 m^3/rev. The tail of the catcher is also a tube of 9 in. diameter, and it may be assumed the flow patterns in it are similar to those in the calibration tube. Therefore, a meter reading of 390 revs./mi. (no net in the catcher) rep-

resents an accepted volume of 390 times 0.114, i.e., 44.3 m^3. Ideally, the valve should accept 64.9 per cent of the volume presented to the mouth, i.e., of 76.7 m^3, which is 49.8 m^3. On this basis the valve accepts water with an efficiency of 89 per cent. Since frictional resistance is introduced by the nets the flow is reduced still further. For the net of 10 meshes per inch, the reduction is 11.5 per cent so that 39.2 m^3 is accepted (78.8 per cent efficient); for the 40-mesh net the volume is reduced by 20.4 per cent which is 35.2 m^3 (71 per cent efficient). (See Fig. 10, upper curve.)

These data demonstrate first, that the narrower aperture of the valve controls the flow of water into the catcher. Second, the nets introduce restrictions to flow, but as their filtering areas are adequate in relation to the area of the orifice controlling the flow, the restrictions do not change with speed, at least between 3 and 10 kt. Third, the catcher deals reasonably efficiently (89 per cent) with a volume of water equivalent to unit length times the area of the valve.

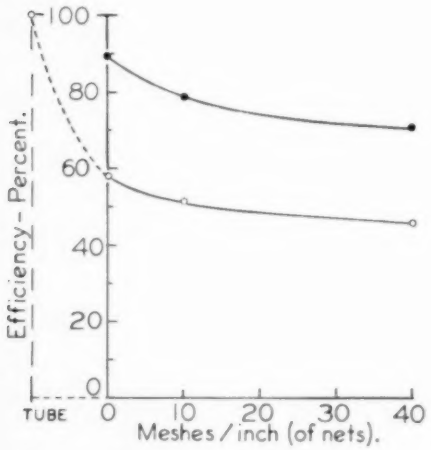

FIG. 10. Lower curve: percentage efficiencies of catcher with no net, and nets of 10 and 40 meshes/inch, relative to the calibration tube (of 9 in. diam.) when this is assumed to accept 100 per cent of the column of water presented to it. Upper curve: percentage efficiency of the catcher with no net (an absolute efficiency 89 per cent for a valve aperture of 7¾ in.), and with nets of 10 and 40 meshes per inch.

Flow Through the Catcher

Flow through the body and tail of the catcher is controlled predominantly by the areas of their cross sections relative to that of the valve. The ratio between the areas of valve and body is 2.75, and between valve and tail, 1.55. If the rate of flow through the valve is assumed to equal the towing speed, then at 10 kt. the flow in the body is 3.65 kt. and in the tail, 6.5 kt. These rates assume an efficiency of 100 per cent by the valve; reduction of flow by the nets, and an efficiency value which is below 100 per cent, will lower them. The moderate rate in the body probably accounts for the undamaged condition of the plankton (see later).

There is probably an optimum rate of flow through the body (and the filter) for most efficient working of the unit. This becomes a factor in any new design which proposes a change in the diameter of the controlling orifice. Thus, an increase in the diameter of the valve to 9 in. (which, it may be assumed, will equalize the volume accepted by the valve and that presented to the mouth) will reduce the ratio between the cross-sectional areas of body and valve to 1.78. Rate of flow through the body would then be 5.6 kt. for a towing speed of 10 kt. Such a rate may damage organisms beyond an acceptable amount, or the frictional resistance of the nets may increase to a degree where it begins to seriously reduce the efficiency of the catcher. It is believed that the diameter of the valve can be increased, but this will probably require the diameter of the body to be increased also, so that flow does not exceed an acceptable speed, say of 4.5 kt. at a towing speed of 10 kt.

Plankton Catching

Trials of the ability of the catcher to collect plankton have proceeded to the extent that circumstances have permitted. It has not been possible to make repetitive hauls in one place

or numerous series of hauls, in order to assess the versatility and reliability of the catching power of the unit. A conventional type of net, of 50 cm. diameter (Bary, 1956), was twice fished alternately in horizontal tows with the catcher, and other horizontal tows have been made with the latter. Some vertical tows with the catcher have been compared with collections from a Nansen-type closing net. Whenever a net has been included during trials with the unit, the bucket has been examined for plankton.

The range of organisms and the quantities collected are most encouraging. Several of the smaller species of pelagic fish, fish larvae, squid, and larger euphausiids and shrimp have been captured. Also, common forms such as copepods, chaetognaths, salps, and larval decapods are collected, sometimes in high numbers. When the catches of the 50-cm. net and the catcher were roughly equilibrated for differences in size of mesh, area of mouth, and distances towed, the catcher was believed to have collected a greater quantity of larger organisms, including fish and shrimp, than the net. Collections made during the vertical hauls with the 70-cm. Nansen-type of net and the catcher were similar in the range of organisms captured. Specimens are alive (except fish larvae) and quite undamaged at towing speeds up to 8 kt.

Although test hauls with the catcher are few, those made to date suggest it collects a representative range of organisms—a range which may be comparable with that taken by the 70-cm. Nansen closing net.

OPERATION

A "high-speed" plankton sampler, as well as being towed at fast rates, must also be quickly and easily handled on deck, recovered from, launched, and lowered to the level at which it is to be towed, and emptied of its catch.

On raising the present catcher from a horizontal tow, the depressor is lifted onto a hook attached to the ship's side (not necessary in calm water), and the rear end of the catcher is rested in the crotch on the guard rail (Fig. 6); the meter is read (or the smoked cylinder renewed), and tail and net are removed. A second net and frame can then be slipped into the body and the tail replaced. The unit is lifted over the side and while hanging free of the rail, the valve is opened. The depressor is then freed, and the whole is lowered into the water. For a team of three (one working the winch), the time taken on this routine is about two minutes. The ship may continue to steam at from 6 to 8 kt. The used net is washed down with sea water from a hose and the catch preserved; the net is then ready for the next tow.

To reach the required depth of a horizontal tow, the catcher is allowed to dive on an almost free-running winch, and a length of wire is veered equivalent to 2.5 times the depth (a ratio of approximately 1:2.5 was found to apply up to 100 m., but may not do so at greater depths. The depth-flow meter provides a check on the depth reached.) Meanwhile the ship may continue underway, altering speed to the towing speed, if necessary. At the end of the tow, the catcher is closed by messenger, recovered, and the usual routine followed.

In vertical tows with a single unit (no tows with multiple units have been made), the routine is similar. Additionally, the wire is released from the after bracket before the tail is lifted onto the rail, and is replaced again before lowering. The terminal sinker need not be lifted, but may require steadying with a strop or boat hook in rough weather.

Lowering for the vertical tow is rapid when compared with a Nansen-type of net. It is necessary to brake the winch to a vertical speed of about 4 kt. so that a strain is maintained on the wire, otherwise the catcher may dive nose first (see earlier). The haul is as rapid as the winch permits, or as is desirable. At depths below 750 m., delays of a minute or two are necessary, before commencing to

haul, because of the falling time of the messenger. However, they do not greatly affect the very considerable saving of time accruing from the relatively rapid lowering, hauling, and recovery of the catcher from, and its return to, the water, during a series of vertical tows.

Before quantitative investigations can approach absolute values, as opposed to relative values, the efficiency and characteristics of the catching gear should be known. Currie and Foxton (1957) have provided pertinent data for their new quantitative (Nansen-type) net, but the equivalents do not seem to be available for high-speed samplers. The meter for such a sampler requires calibrating for flow, but in a situation remote from influences of the gear which may interfere with its functioning (e.g., in a calibration tube), and over the speeds at which the sampler is likely to be used. Values obtained must be considered in relation to the flow through the sampler itself, with and without nets included, and again over the relevant range of speeds. The proportion of the column of water (of unit length and of a cross-section equal to that of the controlling orifice) accepted by the gear under conditions of differing rigs and speeds now can be estimated fairly accurately. That is, the efficiency of the catcher can be determined. The optimum towing speed can now be established, together with the effects on flow of nets of differing meshes, or of clogging. With these data, one may reasonably study whether the catcher is collecting a representative sample of the organisms it encounters, and thus make an appreciation of the true density of the plankton population being investigated.

SUMMARY

A plankton catcher is described which has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. It can be closed during either tow. To convert from the rigging for one type of tow, to that for the other, is rapid and easy and is believed not to alter the catching ability of the unit.

A depth-flow meter is included in the catcher. It has been calibrated by towing first when mounted in a tube of equal diameter to the mouth of the catcher (9 in.), and second, in the catcher, at speeds between 3 and 9 kt. The catcher was towed without a net included, and successively with nets of 10 and 40 meshes to the inch. Data from these tests show that the valve of the closing mechanism (7¼ in. diameter) controls the flow into the catcher; about 89 per cent of the water presented to the valve is accepted. A net of 10 meshes per inch further reduces flow by 11.5 per cent, and one of 40 meshes by 20.4 per cent. Frictional resistance to flow, offered by the meshes, is believed to be responsible as the filtering area of either net is more than adequate to filter the quantity of water presented, at speeds to 10 knots.

Plankton is mostly alive and undamaged. Indications are that a representative range of organisms is being captured, including small squid and pelagic fish and the larger pelagic crustacea.

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Is the Spear of Istiophorid Fishes Used in Feeding?[1]

ROBERT L. WISNER[2]

THE SPORT OF ANGLING for spearfishes—the several marlins and sailfishes of the family Istiophoridae—has fostered many books and articles on the behavior of these large fishes. The swordfish, *Xiphius gladius* Linnaeus, comprising the family Xiphiidae, also commands a very considerable following among saltwater anglers and is the subject of an extensive literature. Certain beliefs have arisen concerning the behavior and habits of the fishes comprising these game fish families, particularly as to their methods of obtaining food. It seems worthwhile to attempt now an evaluation of the accumulated evidence. Only the true spearfishes, particularly the marlins, will be considered in detail. The broadbill swordfish will be mentioned only occasionally, and the conclusions reached do not necessarily pertain to this fish.

Angling lore is replete with reports of such fishes stunning prey and trolled fish baits with a blow of the spear before devouring them. The time-honored belief that the spearfishes possess their spears for the express purpose of striking or stabbing prey, however, may now be questioned. Recently accumulated evidence indicates that such fish can exist quite readily without a spear to aid in obtaining food. Other evidence has cast some doubt as to whether the spear is at all commonly employed in such a manner.

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RECORDED OBSERVATIONS OF FISH WITHOUT SPEARS

Moore (1950) reported on a spearless black marlin, *Makaira mazara* (Jordan and Snyder), that was landed at a commercial fish market in Honolulu, Hawaii, without indicating the length of stub remaining. The nature of the wound indicated some time lapse since the loss. The specimen weighed 545 lbs. and was judged equal in physical condition to normal fish of the same species.

Mr. Vernon E. Brock, Director, Division of Fish and Game, Hawaii, in correspondence reports ". . . a spear removed from a marlin which has been broken with the remaining part that is spiraled like a corkscrew. The fish from which the spear was taken was, according to the fishermen, normal in all respects."

Morrow (1951) reported that a 172-lb. striped marlin, *Makaira mitsukurii* (Jordan and Snyder), taken with sporting tackle and trolled bait at Otehei Bay, New Zealand, had the spear broken off on a long slant reaching from several inches behind the mandible tip to within a few inches of the eye. The break had completely healed and was well covered with skin. The injury had affected the fish further in that the mouth was prevented from closing completely, one side remaining partly open. However, the fish appeared to have had no difficulty in taking the bait and gave a battle said to have been entirely normal for a fish of its weight.

Farrington (1942: 110) reported numbers of marlin with spears broken off. This observation was made at Guaymas, Sonora, Mex-

ico. Grey (1926: 105) mentioned a marlin in New Zealand waters that had a broken spear. The region of the break is not indicated, nor is the amount missing. Grey states, "Deprived of his weapon of defense and for procuring food, this marlin might well have been expected to be thin, flat, in poor condition. Nevertheless, he was solid, fat, in splendid shape. He had been compelled to rely on his speed."

In September, 1952, the author examined two spearless striped marlin at the Marlin Club dock at San Diego, California. Each was captured with sporting tackle and trolled bait. Each spear had been broken off at about the tip of the lower jaw, as in Figure 1. Since both stubs had healed completely and were well covered with skin, a considerable time must have elapsed since the injuries. The fish weighed, respectively, 149½ and 186 lbs. (official club weight). These fish were of at least average weight for their length (Fig. 3). Morphometric data obtained on both specimens when compared with those of normal fish of the same body length and weight disclosed no significant differences in body proportions.

The stomach contents of the smaller fish comprised the remains of 8 Pacific sauries, *Cololabis saira* (Brevoort), totalling 349 cc. The larger fish contained 5 small yellowfin croakers, *Umbrina roncador* Jordan and Gilbert, totalling 785 cc., a small halfmoon, *Medialuna californiensis* (Steindachner), 105 cc., and 1 trunk section of a Pacific saury, 23 cc. The first fish had eaten a main item in the diet of local marlin, as determined by Hubbs and Wisner (1953), but its stomach contents were of less than average volume. The second had eaten more than an average amount, but chiefly of a shore species not otherwise encountered in the food studies.

A third spearless striped marlin was landed at the San Diego Club on September 17, 1955. This fish was not examined by the author, but was reported to have been normal in all respects and fought strongly. The stub was reported to be smoothly healed and covered with skin. A fourth spearless fish, landed in September, 1956, also was reported to be quite normal despite its loss of spear. This fish also was not examined by the author.

FIG. 1. Spearless striped marlin, weighing 149½ pounds. Photographed at the San Diego Marlin Club, Sept. 13, 1952, by R. Van Nostrand.

Gudger (1940) cited many examples of portions of spears having been broken off at a considerable period of time before capture. All these fish had apparently survived the wound and had flourished since. Unfortunately, most reports did not estimate the amount of spear missing. One account ap-

proaches the incredible. During the Michael Lerner Australian-New Zealand Expedition, Miles Conrad reported seeing a marlin with the spear sawed off, and yet the fish had survived. The spear had been removed by a square cut about midway between the tip of the lower jaw and the anterior edge of the eyes—the point generally selected for sawing off a spear trophy. The fish had evidently been caught by an angler, and, when the spear had been removed, had escaped to the ocean. The growth of skin that had formed over the stub still retained the rosy glow of healthy healing. The fish was reported to be thinner than a normal fish of its size. Without doubt a fish so injured as to leave the upper half of its mouth permanently open with but half an upper jaw would be seriously handicapped in feeding. The previously cited injuries had at least left the fish with mouths somewhat suited for grasping and holding prey.

As stated by Morrow (*op. cit.*), "It is obvious the spear is not absolutely essential to the well being of the spearfishes." The four specimens under the immediate cognizance of the author, as well as those reported by Moore, Morrow, Brock, and Gudger, had apparently existed in normal fashion despite the loss of the spear. None of those taken on sporting tackle had given any marked indication of weakness, or other abnormal behavior attributable to loss of the spear, while striking the trolled bait or during the ensuing battle.

RECORDED FEEDING AND BAIT-SEIZING HABITS

The fact that marlins can exist reasonably well without their spears reopens the question of how spearfish feed. Many anglers and authors of books on angling for the large game fishes have given accounts of spearfishes stunning their prey and trolled fish baits with a slashing blow, before turning to devour them. The angling methods for these fish have long involved a slack line arrangement to allow the bait to lie "dead" in the water following the initial rush or strike of the fish.

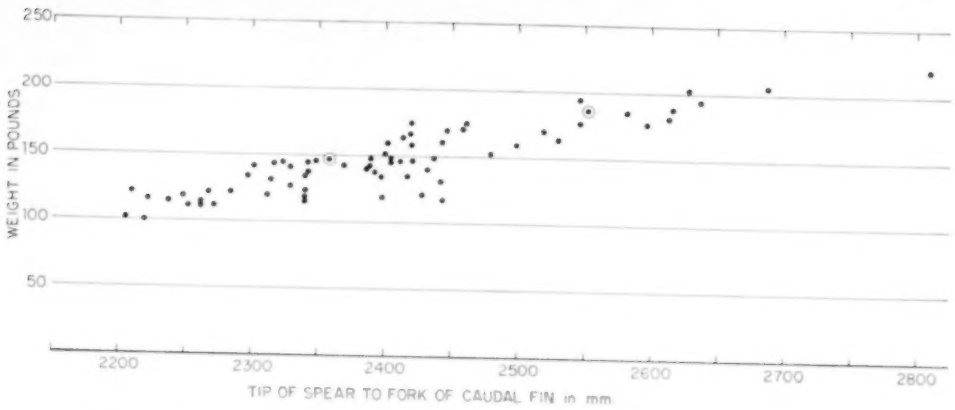

FIG. 3. Relation between weight and length from tip of spear to fork of caudal fin for striped marlin caught near San Diego in 1952. The two circled entries are for the two spearless fish caught that year. Their lengths are computed by adding the average length of spear from tip of mandible for other marlin of the same length behind tip of mandible. The two spearless fish are at least average weight.

According to Van Campen Heilner (1943: 108–109) almost no spearfish were taken in Florida waters before the discovery of this method by the famous Captain Bill Hatch of Miami, Florida, while experimenting with methods of raking sailfish. Heilner stated that Hatch, the father of the "Drop-back," came to the conclusion that, "When the sailfish first rushed the bait he struck it a blow with his spear to stun it and if it didn't collapse then and there, something was phoney. By immediately allowing a lot of line to run off the reel the sailfish was fooled into believing he had paralyzed his prey and would return to seize it." Prior to the use of this method the sailfish only mauled the fish being used as bait for kingfish and mackerel but could not be hooked, which may indicate that the sailfish were grasping the bait between their jaws rather than striking it with their spears and that the bait was pulled from their jaws or rejected before it could be swallowed.

It is known, of course, that marlin in particular do not always strike a blow before taking the bait. A fast rush and grab is most frequent. A hungry fish, of course, is much less apt to toy with a bait or prey than to make haste in consuming it. Thomas and Thomas (1930: 130) cited a fish that did not attempt to stun the bait with the spear. "The marlin changed direction in his rush and, just before he reached the lure he swerved to one side, as such fish nearly always do, and seizing his prey between his jaws, whirled, splashed a trifle, and, like a ray of light as he showed his gleaming underbody, turned downward and was away." In another connection (p. 122) these authors stated: "When marlin hit a troll they do not grab it in their mouths as do other fish; rather they seize it between their upper and lower bills before swallowing, and seem to approach the lure sideways, turning it before gulping it down." Bandini (1933) lent support to this opinion by stating, "A marlin seizes the bait crossways in his mouth and swims away with it."

In contrast to the foregoing testimony, Thomas and Thomas described the feeding habits of marlin as follows (p. 121): "They feed chiefly on anchovies, sauri [*sic*], sardines, flying fish, and other small fry, charging into schools of these unfortunates and slashing

FIG. 2. Striped marlin with a deformed spear. Photographed at Mazatlán, Sinaloa, México, Mar. 26, 1954, by R. L. Wisner.

right and left with their bills, before turning back and leisurely picking up those they have killed or crippled." Another report by these authors (p. 136) was that: "Marlin were everywhere, scattering bait and cutting the water with their fins and tails .... Terrified patches of bait skittered across the water endeavoring to elude their pursuers who slashed relentlessly."

Voss (1956) has contributed the following information. "How well the sailfish uses this weapon I discovered one calm winter day off Stuart, Florida, when we backed our boat into a school feeding on minnows. The sailfish circled slowly, sails half raised, herding their prey tighter and tighter. First one and then another broke from the circle and swam through the milling prey, thrashing right and left with their bills. Then the predators would submerge and lazily eat the dead and stunned minnows as they drifted down."

It is, of course, possible that a difference exists in the method of capturing trolled baits and free-swimming prey, even though the spearfishes may be facile in each method. One must give complete credence to such observations as made by Voss. It is evident that on occasion, abnormal though it may be, the spear is used to obtain food by thrashing. However, the mass of observations indicate this to be a rather infrequently employed method. The following observations from the field and from studies of stomach contents shed considerable light on the matter.

In examining the stomach contents of many marlin, the author has at times noted that the heads and pectoral regions of some of the less digested specimens had been severely damaged on both sides, presumably as a result of having been crushed between jaws. Along the same line Thomas and Thomas (*op. cit.*, p. 124) stated that "the bills [upper and lower jaws] of a marlin leave two distinct depressions on a small fish just behind the gills." These observations indicate that, at least at times, the struggling prey is seized so as to kill it, or to hold it firmly preparatory to swallowing it. The observations also indicate that in such situations the spear is not used to obtain food. If the prey had been killed or stunned or so injured as to prevent escape the marlin would not have needed to crush the prey before swallowing it.

That marlin can feed without the use of the spear is demonstrated by the following statement by Miss Francesca LaMonte of the International Game Fish Association (quoted by Hubbs and Wisner, 1953): "Dr. D. G. Maitland of Sydney, Australia, has recently written us as follows: 'It may interest you to know that I have actually watched a pair of Black Marlin feeding upon *Physalia*, like huge Rainbow Trout taking flies, and absolutely ignoring a most tempting looking mackerel bait drifting in front of their noses.' "

That prey much larger than the small coelenterate of the genus *Physalia* may be captured without obvious use of the spear is indicated by another observation. During preliminary studies of the food of striped marlin in the San Diego area in 1952, a young blue shark, *Prionace glauca* (Linnaeus), a little longer than 24 inches, was found in the stomach of a 205-pound marlin. This shark, which had been recently ingested bore no marks of a blow or thrust of the spear. A roughening of its skin over rather broad areas could have been produced by the sandpapery jaws of the marlin as it grasped and held the struggling shark. A blow, or blows, of sufficient force to kill or stun the notoriously hard-to-subdue shark would almost certainly have left identifiable marks on the body.

Still another indication of feeding that certainly would not call for use of the spear was encountered by the author while examining striped marlin stomach contents at Mazatlán, Sinaloa, México, in March, 1954. Both marlin and sailfish were feeding on a species of argonaut. Such a relatively slow-moving mollusk would be as easily captured as *Physalia* and would require not even the lightest tap from a spear.

Until very recently none of the studies of the food habits of marlin has disclosed any ingested fish that show the marks of having been slashed by or impaled on the spear. Hubbs and Wisner (1953), for example, found no evidence of fish having been damaged by the spear. A more definitive study of stomach contents for the 1952 and 1954 seasons in San Diego has substantiated these findings. Miss Francesca LaMonte (correspondence) states: "In no case have I ever seen anything that seemed to have been slashed by the spear or impaled upon it."

RECORDED USES OF THE SPEAR

The fact that the spear has been retained since possibly Upper Cretaceous, and certainly since Eocene times (Berg, 1940), indicates that it is much more of an aid than a hindrance to the fish. That the spear may, on occasion, be used to obtain food by stabbing, or as a weapon, is illustrated by the following observations. Anonymous writers (1955*a*, *b*) recorded that during a cruise into tropical waters south of Hawaii, "An interesting incident was the landing of a huge white marlin [*Istiompax marlina* (Jordan and Snyder)], estimated to have weighed around 1,500 pounds, which had in its stomach a freshly killed yellowfin tuna 5 feet in length and weighing 157 pounds. . . . The tuna had been speared clean through its body twice before being swallowed."

Another such observation from Hawaiian waters, again provided by Mr. Vernon E. Brock (correspondence), is as follows, ". . . the use of the spear to stab another fish does occasionally occur. One such observation by the skipper of the territorial research vessel was made off the Kona coast of Hawaii a number of years ago when a marlin was observed at the surface of the sea with its spear thrust through the body of a dolphin [*Coryphaena hippurus*]. The dolphin was struggling vigorously and the marlin would rear out of the water in an apparent attempt to prevent the flopping fish from working free of the spear."

Zane Grey (1926: 48) reported finding a snapper with a round hole in it in the stomach of a marlin caught in New Zealand waters. In Tahitian waters Grey (1931: 229) quoted Captain Mitchell, his fishing companion, as reporting his bonito bait rammed clear through by a marlin. Farrington (1937: 221) reported big dolphin "batted" into the air by marlin and that numbers of dolphin have been caught that had holes in them where marlin spears had pierced them.

This author has very recently studied a frigate mackerel, *Auxis* sp., and a sierra mackerel, *Scomberomorus sierra* Jordan and Starks, removed from marlin landed at Mazatlán, Sinaloa, México in March, 1954. These fish, respectively 300 and 430 mm. long, each bore the marks of a spear thrust through the midsection, respectively above and below the lateral lines. Each fish was removed by the author from undamaged, freshly caught striped marlin and wrapped and stored until studied. Unquestionably, the marks were made by spears as the holes were large and had been torn out through the dorsomedian flesh of the *Auxis*, and through the ventromedian flesh in the *Scomberomorus*. Several other fish of the same species groups and similar in body sizes bore no marks of the spear.

Gudger (*op. cit.*, pp. 271–274) cited several reports from reputable observers which indicate that battles occur between swordfish and spearfish, and between members of these two families and sharks. Broken spears have been found imbedded in the flesh of each, some obviously having been there for some time. Voss (*op. cit.*) reported catching a sailfish that had the broken bill of another sailfish projecting [through the body] on either side.

SPECULATION ON THE USES OF THE SPEAR

It seems probable that the spear is used both as an aid in food-getting and as a weapon. It is a rather moot question whether the cited stabbings and "battings" of larger fish

resulted from pugnacity, playfulness, or a desire to obtain food. The 157-pound tuna could conceivably have been regarded as an enemy by even a 1,500-pound marlin. The big dolphin would not seem to fit the enemy category although the relative sizes of prey and predator were not given. If it may be assumed that marlin customarily charge their prey to engulf it, it is then possible that the stabbings were accidental. If a spearfish is able to overtake its prey with sufficient speed to impale it, such speed should be more than adequate to permit the prey to be seized. Accidental stabbings of the smaller prey seem quite plausible if one considers the almost phenomenal accuracy required of the predator to hit and penetrate even an unsuspecting prey. In line with this view, impaling an evasive prey appears to be governed by chance. The few observations of stabbing make it seem possible that the spear may be used against the larger fishes—those not readily captured by overtaking and seizing between jaws.

The preponderance of evidence indicates the spear is not commonly used as a means of getting food. The food content studies to date have all dealt primarily with smaller forage animals. Presumably few others have been found. One must conclude that these comprise the bulk of the food of the spearfishes. As stated earlier, few indications of stabbing and none of injury by blows have been found. The prey had evidently been overtaken and engulfed by the predators. Those spearfish found with the spears missing had almost certainly employed this method of getting food.

Examination of the spear and jaws indicates that the smaller forage fish and squid, the prime components of spearfish food, could not readily be stabbed. The spear is relatively dull at the tip and is covered by minute, sharp, backward-pointing nodules for its entire length. These nodules continue to each jaw, where they become a raspy band of teeth. The roughness of the spear covering is attested by fishermen who almost invariably wear gloves to avoid having their hands abraded while the fish are being boated. It would be difficult indeed for the dull tip to penetrate small fish. Certainly the soft, flexible body of a squid would be extremely difficult to be impaled or to be dealt a damaging blow with so blunt a weapon. The swordfish has a smooth, laterally flattened sword of proportionately greater length than that of the spearfishes, but it is equally blunt at the tip. It is better suited as a flail but no better suited for spearing small prey. A striped marlin poorly suited for stabbing prey was observed by the author at Mazatlán, México, 1954 (Fig. 2). The curve of its spear was such that a thrust would tend to slide off a relatively small fish.

Further evidence that the spearfishes do not commonly slash with their spears is found in their skeletal make-up. The construction is not suited to free and extensive sidewise motion. The istiophorids have heavy, flat, platelike neural and hemal spines rather than the common rodlike spines of other fishes. The neural processes are modified into broad platelike structures that extend far forward, almost reaching the middle of the preceding vertebra. The platelike hemal spines are firmly attached to the hemal processes of the neighboring vertebrae, as are the neural spines and processes. Such construction produces an exceptionally strong and inflexible, interlocking, bracing system. The vertebral column of the broadbill is less interlocked but is so fashioned as to resist greater shock from head-on encounters than is that of the spearfishes.

Nakamura (1938), who studied the skeletons of many spearfishes, concluded that "The vertebrae are most unsuited for precise movements, and sudden changes of direction are probably impossible." Furthermore, the deep and flat lateral surface of the anterior part of the body would require tremendous energy and leverage against the resistance of the water to accomplish a slashing movement

sufficiently rapid to strike a small fish fleeing for its life. Such great expenditure of energy would detract from the forward speed of the spearfish, bringing it to a virtual standstill and allowing the prey to escape with but little damage.

It is more reasonable to assume that when a spearfish charges into a school of forage fish the slashing motion observed by many fishermen is really a slight changing of direction and a grasping for the fleeing prey, the head and body describing a relatively small arc. Such a grasping motion is not be to identified with any such deliberate slashing as Voss (*op. cit.*) reported for sailfish. In his observation the prey was herded into a tight school. The speed of the predators was not mentioned. They merely swam into the closely packed school, held together by the remaining sailfish (of unreported number), and thrashed with their spears. Presumably all energy could be utilized solely to kill fish rather than be expended in pursuit.

It must be assumed that spearfish are not always able to concentrate their prey in such fashion. In a less dense and guarded school of prey, and certainly in a very scattered school, it would not be advantageous to merely slash. It is entirely possible that the normal procedure is to charge into the school rapidly snapping the jaws and reaching, within physical limits, for as much prey as possible, with the result that many of the small fish are killed or wounded before the school scatters. Any effective striking with the spear that may occur is probably a secondary and fortuitous event. After the school has scattered the spearfish would likely see the wounded or killed fish and would return to ingest them.

These large fishes are obviously built more for forward speed than for marked agility. It is entirely within reason to assume that a spearfish can readily overtake any of the forage fishes or squid, which constitute the bulk of its food, and most of the larger fishes. A conservative estimate of their speed is at least 25 miles per hour and bursts of much greater speed are probable. A hooked sailfish was clocked at 100 yards in three seconds, or approximately 68 miles per hour (Walford, 1937).

The enormous speed and power of spearfish are dramatically attested by the puncturing of ship hulls. Gudger (1940) reported, with documentation and photographs, many spears found in wooden and copper-clad hulls of vessels. Some of these had penetrated fantastic thicknesses of timber and had broken off to furnish irrefutable evidence of speed and power. One remarkable example follows: "The spear was found to have penetrated through the copper sheathing, an inch board sheathing, a three inch hard wood plank, the solid white oak timber of the ship 12 in. thick, through another two and a half inch hard oak ceiling-plank, and lastly had perforated the head of an oil cask, where it remained immovably fixed so that not a single drop of oil had escaped." This total of 18.5 inches through hardwood, 14.5 of it through dense oak, was accomplished by a spearfish as the recovered spear was round, unlike the flattened blade of the broadbill swordfish.

San Diego based wooden-hulled fishing vessels have at times been placed in danger of sinking by these fish. The tuna vessel "Rose Ann" (San Diego Union, 24 Oct., 1946) was struck three feet below the water line off Punta Abreojos, Baja California, and was forced to use both bilge pumps constantly to remain afloat. Subsequent investigation revealed five inches of marlin spear projecting through the hull planking. Fishermen recalled that other vessels in 1942 and 1946 had suffered the same type of damage. Another recorded ramming occurred off Ecuador, involving the tuna vessel "Renown" (San Diego Union, 22 Aug., 1948). Pumps were operated continuously during the homeward voyage. When the hull was inspected 18 inches of marlin spear was found projected through the 3-inch hull planking, forming a crack an inch wide.

There are further indications of the speed and power of marlin, and possibly of their pugnacity. Morrow (1951) reported having seen on a beach in British East Africa a bale of crude rubber that held the broken spear of a black marlin imbedded 8 or 10 inches into rubber so tough a man could not drive a spike into it with a heavy hammer. Smith (1956) reported on floating rubber bales from the African coast. As many as four spears have been found in one bale. Another bale contained 24 inches of the spear of a large black marlin embedded to a depth of 13 inches. In one bale was found the sword of a broadbill swordfish, indicating that it also charges floating objects

The reasons for these attacks are not completely understood. Some may be the result of sheer pugnacity. However, it has long been known that fish often lie beneath floating logs, debris, ship hulls or any fairly large, slowly moving object at or near the surface. The tuna live-bait fishermen make a practice of fishing, often with considerable success, close to such objects, including the large whale shark, *Rhincodon typus* Smith. The ramming of ship hulls may well be the result of excess speed and a lack of maneuverability of the attacker as it charges to engulf fish lying under such shelter.

Gudger (*op. cit.*) supported this view with an observation by F. D. Bennett (Narrative of a Whaling Voyage Round the Globe, 1833 to 1836, London, 1840). Bennett tells of albacore [*sic*], clustering in a dense shoal under the ship, that "swam with an appearance of trepidation and watchfullness. The cause of this unusual commotion was visible in a swordfish, lurking astern, awaiting a favourable opportunity to rush upon his prey when they should be unconscious of danger or away from the protection of the ship. . . . and in the course of the day we observed him make several dashes amongst the shoal with a velocity which produced a loud rushing sound in the sea. . . . It is probable, as a precaution against the attacks of this monster, that albacore, and some other tropical shoal fish, attach themselves to ships, . . . , the close vicinity of a large body being sufficient to deter the swordfish from making his usual impetuous thrusts amidst the shoal; the which, when rashly attempted, have given rise to the appearance of the broken rostra of these fish impacted in the planks of ships, . . . as is not unfrequently noticed." Although the name "swordfish" is used it may also have been a member of the round-speared Istiophoridae, as all were termed swordfish until recent years.

Certainly no flailing at prey could have resulted in such penetrations of hulls as recorded. The angle of incidence of spear and hull would either have deflected the spear or have caused only slight penetration. Also, if the spearfish had concentrated on a side-to-side motion, the greater portion of the total energy would have been expended in this action. The forward speed would have been correspondingly reduced, so as to lessen the depth of penetration, regardless of the angle of incidence. Only a straight-forward charge resulting from pugnacity or an attempt to capture prey could result in such penetrations.

The biological significance of the spear may well be an adaptation for the great speed and power of these large fish, as well as a weapon of defense or attack. I am indebted to John D. Isaacs and Carl L. Hubbs for the following suggestions. A terminally opening mouth would create enormous drag and would push in front a mass of water at a similar speed, so that a spurt of the intended prey would lead it to safety. If the mouth were terminal the common mode of ingestion by suction due to a sudden spreading of the gill covers as the mouth is opened would probably be difficult and perhaps dangerous at extreme speeds. On the other hand the projecting and tapered spear would scarcely impede the flow of water past the narrowly triangular mouth on the lower surface of the base of the beak. A sudden snapping of the sharply pointed inferior mandible would induce minimal drag and would be effective in

grasping prey. If the spear is of use in feeding, it is probably of most value in permitting high speeds to be attained by the feeding fish.

It may be argued that the tunas and porpoises are also rapid swimmers yet have terminally opening mouths. However, they too are well streamlined and have relatively narrow snouts that no doubt induce minimal drag at high speeds. Indeed, their spearless heads may be considered analagous to those of spearfish without spears. There is little doubt but that the tunas and porpoises rely on speed to capture prey.

SUMMARY AND CONCLUSIONS

It is concluded that the spearfishes rely primarily on speed to overtake and engulf their food. This circumstance explains why spearless marlins are able to obtain food and to exist in competition with their undamaged fellows. The widely held belief that these fishes, marlins in particular, normally stun prey with a blow of the spear has presumably stemmed from fishermen watching fish turn slightly to grasp the bait between jaws or to engulf it, during which action the spear performs a lateral motion readily interpretable as a slash or blow. The several instances of stabbings of prey may well have resulted from the high speed of the predator and escape attempts of the prey, the spear point inadvertantly striking the prey. There is little to indicate that most stabbings are intentional. In the face of preponderant evidence that most of the prey is not stabbed, one must, for the present, accept the probability that such spear penetrations are quite accidental.

Further evidence that these fishes rely on speed to overtake prey are the numerous accounts of the ramming of ship hulls and floating objects. It seems logical to assume that many such rammings result when spearfishes charge prey lying under these vessels and either fail to see the hull or misjudge the distance between prey and hull. The depths of penetration strongly indicate that the spearfish was not using its spear as a flail to obtain food. Such penetrations of objects could have resulted only from a straight-forward charge, either to seize the prey lying underneath or to battle a fancied enemy.

The restrictions in rapid lateral movement imposed by the highly integrated and reinforced vertebral column render it highly improbable that such fishes normally kill or stun prey by slashing with their spears, particularly when in pursuit of fleeing prey. The roughened surface of the spear and its relatively blunt tip preclude the possibility of stabbing the smaller fishes and the squid, which comprise the major food items of the spearfishes.

In whatever way it is used, the spear presumably serves a hydrodynamic function, increasing the speed of these large fishes. In feeding it presumably does more. The form of the spear and of the adjacent parts of the head seem well fitted to avoid drag, escape of prey, and possible injury at high speeds when the mouth is opened. A rapid water flow is induced past the mouth region, and the mouth appears to be so formed as to present minimal resistance when closed and but slight resistance when opened to seize prey.

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Magnetic Spherules in Deep-sea Deposits

HANS PETTERSSON and KURT FREDRIKSSON[1]

FEW OF THE COMPONENTS entering into the sediments covering the ocean floor have attracted so much attention as the magnetic spherules first described in 1876 by Sir John Murray. Struck by the resemblance of their surface structure to that of iron meteorites, Murray called them "cosmic spherules." The number he was able to extract from one quart of the deposit, by means of a small magnet, varied from 20 to 30 in samples of Red Clay, whereas in the same quantity of Globigerina Ooze only one or two were found (Murray, 1876).

Together with A. F. Renard, Murray later published (1897) a more detailed description of the spherules in volume 4 of the "Challenger" Reports, *Deep Sea Deposits*. The higher numbers found in the Red Clay are ascribed to its much lower rate of sedimentation.

Hoping that the method of counting the magnetic spherules present in different kinds of deposits may afford a solution to the difficult problem of determining the rate of deep-sea sedimentation, one of us decided to include in the equipment of the Swedish Deep-sea Expedition (1947–48) special corers of wider diameter than those otherwise used from the "Albatross," viz., with an internal diameter of 90 mm. instead of the usual 46 mm. For various technical reasons this wide-bore corer was not used until we reached the western Pacific Ocean (Pettersson, 1956). Owing to the higher resistance offered by the sediment to a thick coring tube, and owing to the necessity of avoiding too heavy a strain on the steel cable used when coring, the length of the thick corer had to be limited to only 6 metres, as compared to the 15 to 20 metres of the narrower coring tubes. The length of the thick cores raised was, therefore, in general only 5 to 5½ metres. On the other hand, from a section taken from a thick core about four times more material was obtained than from a narrow core of the same length. In all, a dozen of such thick cores were raised from the cruise with the "Albatross" through three oceans.

Owing to more pressing work on other material collected during the cruise, the working up of the thick cores for magnetic spherules had to be postponed for several years after our return from the expedition. However, in the meanwhile a young technician, T. Laevastu, then in the employ of the Oceanographic Institute in Göteborg, was charged with carrying out preliminary extraction experiments using parts of a narrower core of Red Clay raised from the central Pacific Ocean. For this work an electromagnetic extractor of high efficiency had been obtained from the well-known New York firm of Frantz. Portions of the sediment suspended in water were passed through this extractor. Already in the preliminary experiments with this instrument its great superiority over the primitive method for extraction used by Murray was apparent, the number of spherules extracted from 1 kg. of Red Clay varying between a few hundred and a couple of thousands. Attempts to estimate the efficiency of the method were also carried out by adding to sediment already extracted a counted number of artificial magnetic spherules, made from iron wire with the oxygen flame, having slightly larger dimensions though than the

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natural magnetic spherules found in the sediment. The yield was found to exceed 90 per cent. The results from the preliminary investigation, including a graph showing the size-distribution of the natural spherules, has been published by Laevastu together with Prof. O. Mellis of Stockholm (1955), who had given him valuable help in the microscopical study of the spherules.

Our first objective when starting our work in November, 1954, was to perfect the method of extraction, involving also the preparation of the sediment samples obtained from the cores. The details of this preparatory work, carried out in the Oceanographic Institute with the excellent help of Mrs. Karin Romlin, technical assistant, will be given in a future publication by one of us. It will suffice to mention here that we found it necessary to pass an aqeous suspension of a quantity of the sediment, weighing from 200 to 700 grams (with the narrow corer the sample weight varied between 20 and 300 gr.), at least three times through the extractor. From the magnetic particles thus obtained, which comprised also a large proportion of nonspherical particles of terrestrial origin (largely magnetite), those with strong magnetic properties were separated out by means of a small electromagnet and then passed through sieves of different mesh, separating out the three size-classes: coarser than 60 μ, 60 μ to 30 μ, and less than 30 μ in diameter (see Figs. 1 and 2). The products from this fractionation were then mounted between glass discs in a manner suitable for counting under the microscope. This latter operation was made by one of us in Stockholm, more recently assisted by fil. kand M. Nilsson.

The operations required for a detailed examination of the spherules, like polishing, X-ray examination, etc., were carried out in the Mineralogical Institution of Stockholms Högskola (Fredriksson, 1956). To its director, Professor S. Gavelin, we are much obliged for his support and advice. We are also indebted to Professor F. Hecht of the II Chemisches Institut der Universität Wien, for kindly carrying out for us micro-analyses for nickel and cobalt on some of the spherules submitted to him. His results proved nickel to be definitely present in a percentage varying between 6 per cent and 15 per cent of the iron content. Recently Dr. A. Smales at Harwell kindly investigated samples of deep-sea spherules for nickel and cobalt by means of neutron-activation in the pile.

In order to get comparable results from one sample to another, we found it advisable to concentrate the counts on black spherules of a diameter exceeding 30 μ. The spherules smaller than 30 μ are difficult to count and easy to overlook. Their contribution to the total weight of the spherules appears insignificant. Spherules of the greatest size, i.e., from 60 μ to 250 μ were also counted. Their contribution to the total number of spherules is not great, but, owing to their large size, their contribution to the total weight is considerable.

The following table gives a survey of the cores from which we have extracted and counted spherules.

COMMENTS

CORE 71. This core is of special interest, as it was raised from the vicinity of Challenger Station 274 (S 07° 25′ W 151° 15′) where the depth was 2,750 fathoms or 5,030 m. The sediment in the surface has been characterized by Murray and Renard (1897) as Radiolarian Ooze with 3.89 per cent $CaCO_3$. The core raised from the "Albatross" has a total length of nearly 10 m., from which sections of 26 to 76 cm. in length were taken.

The number of spherules per kg. of sediment, free from salts and lime, varied from a maximum of 1,400 near the surface to a minimum of slightly more than 100 per kg. A second maximum of 600 spherules per kg. appears at the 10 metre level. Control counts made on halves of the section, cut lengthwise, gave fairly large variations in the proportion

TABLE 1

CORE NO.	DIAM. OF CORE, MM.	LENGTH OF CORE IN METERS	LATITUDE	LONGITUDE	DEPTH IN METERS	NUMBER OF SAMPLES
71	46	10.0	S 7°38′	W 152°53′	4990	16
90	90	5.2	S 3°21′	E 174°12′	4830	49
90 B	26	0.3	S 3°21′	E 174°12′	4830	1
92	90	5.2	S 1°20′	E 167°23′	3960	25
133	90	3.3	S 11°33′	E 91°26′	5200	18
187	46	9.5	N 33°59′	E 31°02′	2500	16
17	46		N 43°28′	E 7°22′	2030	1*
18	46		N 41°29′	E 5°51′	2680	1*
87	46		N 2°23′	W 173°50′	5560	1*
89	46		S 2°48′	W 178°57′	5480	1*

* Separate sample from the surface.

of 1:2. The average number of spherules per kg. for the whole core is about 300 (see the curve in Fig. 3).

According to radium measurements, made by Kröll (1955), in the sediment where cores 71 and 72 were taken, the rate of sedimentation is taken to be between 1 and 2 mm. in 1,000 years.

CORE 72. This core was raised from the immediate vicinity of Core 71, where the sediment had the same character. Its uppermost 3 metres, out of a total length of 14 metres, have been examined for spherules by Laevastu and Mellis (4). In Figure 4 the results from their counts are reproduced from their original paper. In Figure 3 the number of spherules is set out for the same levels in which Core 71 has been investigated by us. The figures, however, have been reduced to 50 per cent to be in conformity with our counts, since Laevastu and Mellis included spherules from diameters 10 μ upwards in their counts, whereas our counts in Core 71 are limited to diameters of from 30 μ upwards. According to Laevastu and Mellis the spherules of less than 30 μ in diameter made up less than one half of the total number.

CORE 90. This is a thick core, 90 mm. in diameter. Its total length is, therefore, very moderate, or only 5 metres. In its upper part the content of lime is low, less than 1 per cent. Below the 190 cm. level the content of carbonates increases abruptly to about 30 per cent, rising still further down to more than 80 per cent. The number of spherules varies greatly. From about 3,300 per kg. near the surface, a maximum of 5,000 is reached between 80 and 90 cm. Below the 110 cm. level the number of spherules per kg. of salt- and carbonate-free sediment is less than 1,000 (minimum 140), with the exception of a secondary maximum of 1,300 in a depth of about 280 cm.

Two parallel series of samples from this core were extracted. The results obtained from the first five samples in the first series (see full drawn curve in Fig. 5) were much lower than those from the second series. This is probably due to the fact that the technique of extraction had not been fully developed at that time, so that a certain number of the spherules may have become crushed in the extractor and thus escaped the counting.

In certain samples it proved very difficult to distinguish between different types of spherules, of which the black shiny ones were primarily counted. This difficulty may explain the strong variations found by control counts from identical levels, especially as regards the sample between 63 and 80 cm. In the diagram in Figure 5 these variations are indicated by horizontal lines, uniting the highest and the lowest values found at the level in question.

CORE 90 B. This was a narrow "pilot core" taken from the same vicinity as Core 90. The amounts of spherules in the lime-free portions in the uppermost 4–12 cm. and 0–6.5 cm. of Cores 90 B and 90 respectively were found to

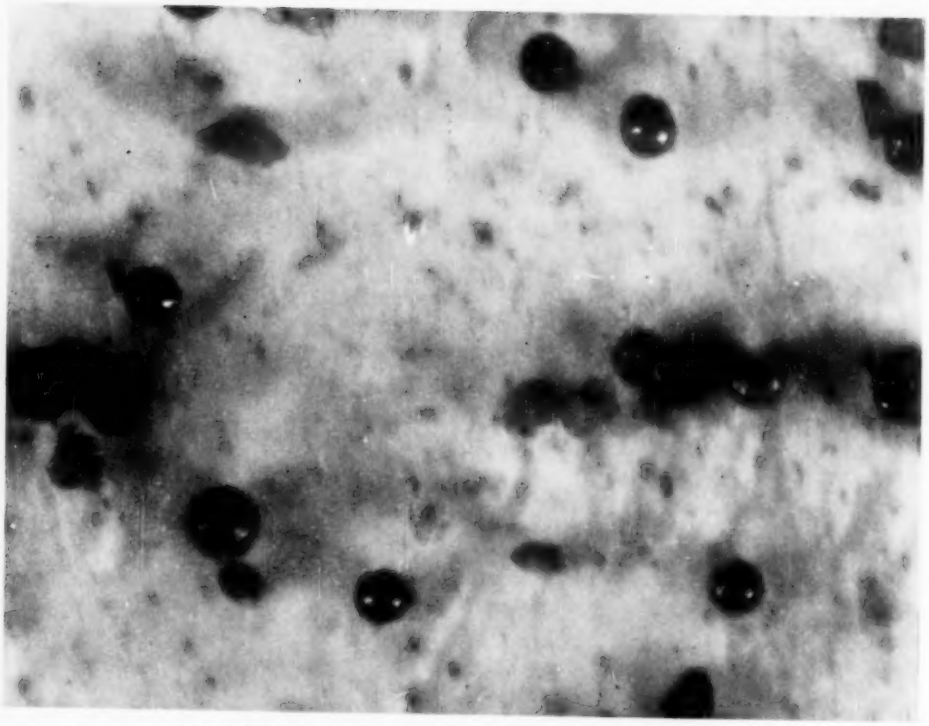

FIG. 1. Spherules from Core 90, about 30 to 60 microns in diameter.

be practically the same. The carbonate content was, however, much higher in the uppermost part of Core 90 B, viz., 56 per cent as compared with the corresponding 0–6.5 cm. of Core 90.

CORE 92. This core, raised from a depth of nearly 4,000 metres close to the Equator, is also one of large diameter (90 mm.) with a length of only 5 metres. The sediment is a calcareous ooze, its content of $CaCO_3$ varying between 71 and 82 per cent. The uppermost 64 cm. of the core were missing, having been lost in transport. The rate of sedimentation can only be tentatively estimated at 50 mm. in 1,000 years.

The number of spherules extracted was very low. Recalculated to 1 kg. of lime- and salt-free sediment, the numbers varied from 0 in a depth of 201–217 cm. to slightly over 200 between 64–81 cm., 231–248 cm. and 275–293 cm. The average for the whole core was 80 spherules per kg. of sediment. (See diagram in Figure 6.)

CORE 133. This core, the only thick core (90 mm.) raised from the central part of the Indian Ocean at a depth of 5,200 m., had a total length of 326 cm., from which the uppermost 3 cm. were missing. Down to a depth of 200 cm. below the top of the core it had a moderately high content of $CaCO_3$, between 14 and 40 per cent, whereas in the lower parts of the core the lime content was only between 5 and 10 per cent, especially near the lower end where it varied over 45 cm. between 5 and 5.6 per cent. The number of cosmic spherules extracted from the uppermost 3–18 cm. was high, viz., nearly 700 per kg., whereas in the lower parts, at depths between 50 and

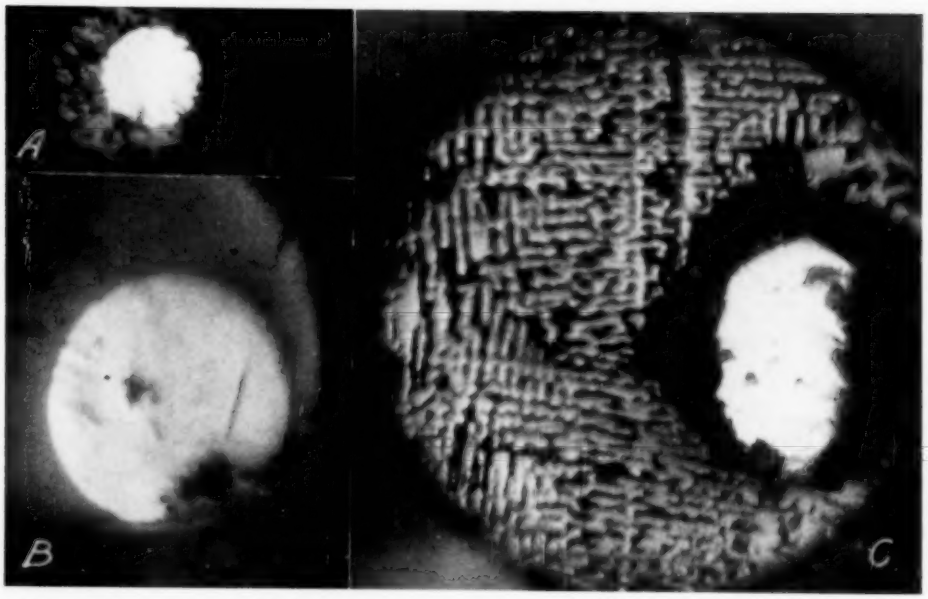

FIG. 2. Polished sections of black spherules. A, spherule from Core 71, about one meter below the sediment surface. Magnetite, gray, with a metallic nucleus, white. Diameter of spherule, 30 microns. B, spherule from the Atlantic Ocean, about 25 cm. below the sediment surface. Same type as A, with imperfect polish. Diameter of spherule, about 80 microns. C, spherule from the same sample as A. Magnetite, gray, metallic nucleus, white. Diameter, 120 microns.

220 cm., the numbers were low, rising again to somewhat higher values below 220 cm. The average number for the whole core was 130 spherules per kg., whereas between 52 and 220 cm. it was only 30, compared to the average for the uppermost 50 cm. of 500 per kg. (Fig. 7).

To ascribe these very remarkable variations in the numbers of the spherules only, or even mainly, to changes in the rate of sedimentation seems unwarranted. That even in the uppermost layers the rate of sedimentation was higher than in the central Pacific Ocean is indicated by radium measurements in a neighbouring short pilot core, Number 133 B, which contained on an average 11 units of the 12th decimal place of Ra$_{gr}$/gr, compared to from 40 to 50 units in Red Clay from the central Pacific. Thus the rate of sedimentation can be estimated for the upper parts of Core 133 at 10 mm. in 1,000 years.

CORE 187. This core, raised from a depth of 2,500 metres in the eastern Mediterranean southwest of Cyprus, was a narrow one and had a total length of 9½ metres. Hence fairly long sections of 30 to 70 cm. had to be used for extracting the spherules. The lime content was moderately high, varying between 20 and 40 per cent of $CaCO_3$. The number of spherules per kg. of lime- and salt-free sediment varied considerably along the length of the core, from 190 near the surface to an absolute maximum of 1,130 in the section 165–235 cm., declining from there, both upwards and downwards, to 5 and 10 per cent respectively of the maximum value.

At another maximum, in section 438–506 cm., 491 spherules were found per kg. of sediment. In the very lowest parts of the core, 860–950 cm., only 38 and 49 spherules respectively were found. It must, however, be emphasized that where control samples from

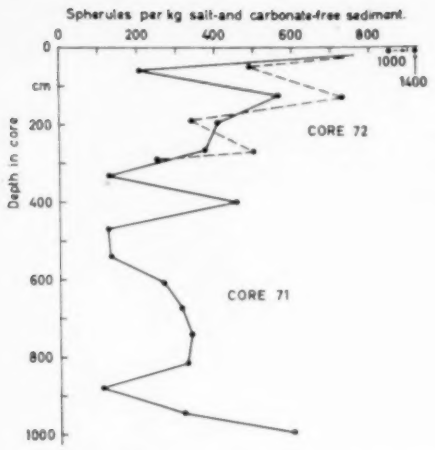

FIG. 3. Number of spherules per kg. of dry substance from Core 71.

the same levels were taken, the values varied considerably *inter se*. The average for the whole core is 190 spherules per kg.

Regarding the rate of sedimentation in this core very little is known. O. Mellis (1954), from a study of the volcanic ash horizons present in cores from the eastern Mediterranean, has identified a layer of volcanic ash in Core 187, situated at a depth of 40 cm. below the top of the core. This layer probably owes its origin to the catastrophic outbreak of the island volcano Santorin, which occurred some time between 1800 and 1500 B.C., i.e., about 3,700 years ago. This assumption would make the rate of sedimentation in the upper layers of the core about 10 cm. in 1,000 years, leaving aside possible disturbances in the sedimentation due to slumping, etc.

Regarding the two maxima found in Core 187, it should be noted that the spherules they contain were especially difficult to identify, resembling some of the samples in Core 90. The values given here must, therefore, be stated with due reserve and have only been indicated in the curve in Figure 8. Nevertheless there is little doubt that the maxima are real, even though the numerical finds are somewhat uncertain. Attempts to find such maxima in other cores from the vicinity are at present being undertaken.

Considering the abrupt decrease in the number of spherules on both sides of the principal maximum, one is tempted to assume that at the time when the maximum occurred one or several meteoritic showers fell upon the eastern Mediterranean. An alternative explanation, that at the time when the maximum occurred there can have occurred an abnormally low rate of sedimentation, appears less probable.

It would be most interesting to investigate other cores, preferably of larger diameter, taken in the vicinity of Core 187.

MAGNETIC SPHERULES FROM THE ATMOSPHERE

The problem of finding by direct observation the amount of magnetic particles settling

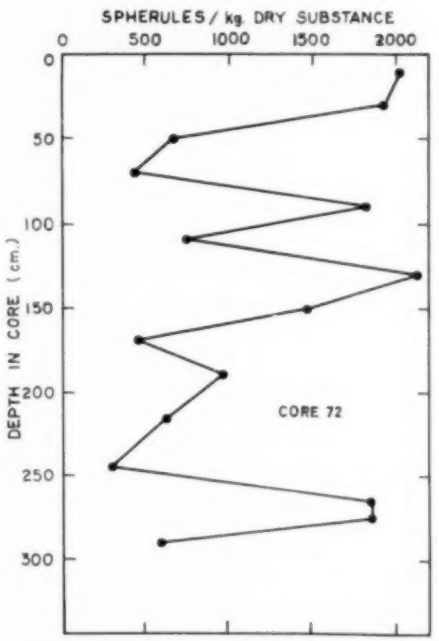

FIG. 4. Number of spherules per kg. of salt- and carbonate-free sediment from Cores 71 and 72.

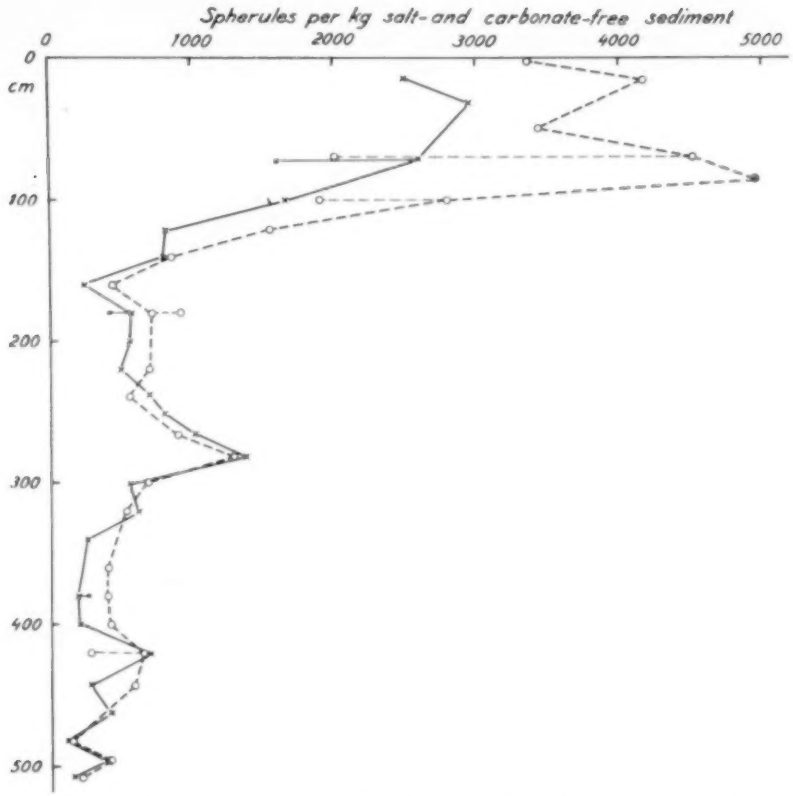

FIG. 5. Number of spherules per kg. of salt- and carbonate-free sediment from Core 90.

on the Earth's surface has repeatedly been attacked by various investigators, mainly in the United States of America. The method adopted has generally been that of introducing magnetic "collectors" into the water spouts carrying rainwater from extensive roofs. The number of magnetic spherules accumulated in this manner has been counted with results which are surprisingly large. Thus Warren J. Thomsen (1953) finds the weight of such magnetic spheres, from observations made at Iowa City, to correspond to a total mass of 2,000,000 tons per year for the whole Earth. Still higher values have been reported by W. D. Crozier (1955) working in New Mexico, viz., 35,000 tons per diem during August 1955, or nearly 13 million tons for the whole year. These figures are several thousand times higher than those obtained from our counts of the spherules in deep-sea deposits. However, neither of the authors mentioned could find any trace of nickel in the magnetic spheres analyzed.

We have tried to collect magnetic spherules by means of magnetic collectors introduced into water spouts mounted at Bornö Station in the Gullmar Fjord, on the west coast of Sweden, and also from the roof of the Oceanographic Institute in Göteborg. At the latter locality we found the number of magnetic spherules collected to be very high, whereas at Bornö the number was considerably less but

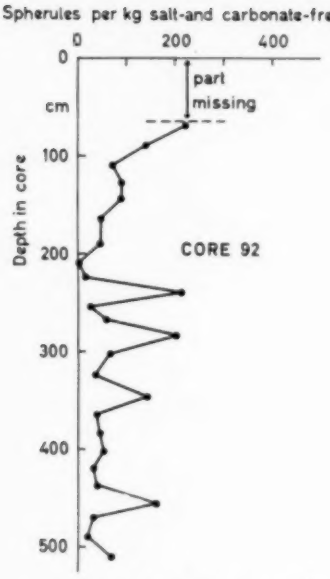

FIG. 6. Number of spherules per kg. of salt- and carbonate-free sediment from Core 92.

still higher than the numbers found in deep-sea deposits. No nickel was found to be present in these spherules.

We infer, therefore, that most of the spherules thus collected are of terrestrial origin and are artifacts from industrial plants and welding operations, which can be carried over large distances by wind.

Hoppe and Zimmerman (1954), collecting magnetic spherules at Jena and other localities in West Germany, have arrived at the same conclusion and consider it impossible to avoid such contamination in localities in or near industrial districts.

Based on these results we have planned to collect magnetic particles from the atmosphere on ocean islands situated far from any industrial plants and as remote as possible from the shipping lanes across the sea. Such measurements, which we hope to organize on Pacific Ocean islands during the Geophysical Year, may be expected to afford evidence of true extraterrestrial spherules settling over the ocean surface and thus complement our studies of the magnetic spherules in deep-sea deposits. Calling attention to the interesting results from the attempts at a magnetic drag over the ocean bottom from the "Galathea" Expedition, we consider the evidence in favour of the magnetic particles reported by A. Bruun and his co-workers (1955) as being largely of cosmic origin to be very strong. On the other hand this method of using a superficial collector can only be expected to bring up extraterrestrial particles of *recent* origin. Moreover, a certain risk of contamination with spurious spherules from coal- or oil-driven ships passing near the course of the "Galathea" cannot be altogether excluded. No such risks are involved when extracting magnetic spherules from undisturbed long cores provided one gets below the uppermost few centimeters of sediment. This method alone seems to allow of definite conclusions regarding the frequency of meteoritic falls and their variations in the remote past.

Quite recently the accruement of meteoritic fragments and dust to the surface of the Earth and its oceans has attracted the interest of meteorologists and climatologists.

Mainly through the work of Bowen in Australia (1953) and of his co-workers in

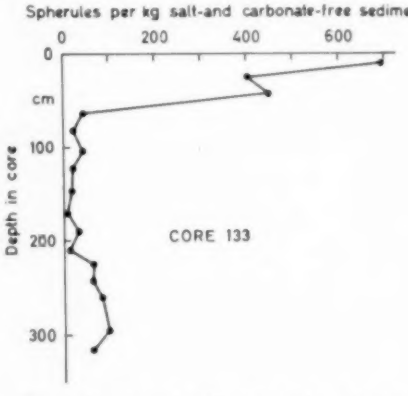

FIG. 7. Number of spherules per kg. of salt- and carbonate-free sediment from Core 133.

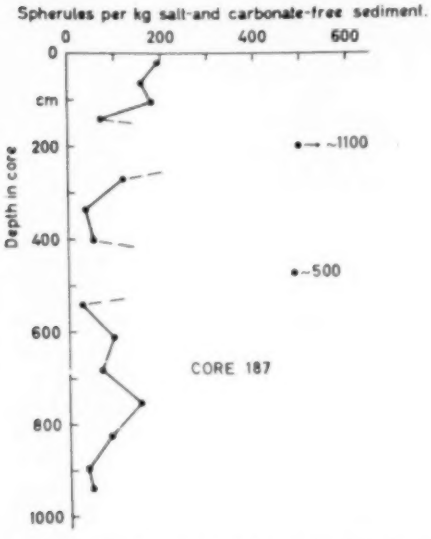

FIG. 8. Number of spherules per kg. of salt- and carbonate-free sediment from Core 187.

different parts of the world (Bracewell, 1954) strong evidence has been produced for the influence of cosmic dust as condensation nuclei for raindrops. According to these finds there occur distinct maxima of precipitation on certain dates like January 12, 22, and 31 to February 1. These peaks of rainfall occur 29 to 30 days after the Earth has passed through meteor showers. According to Bowen the dust into which these meteors are dispersed at great heights in the atmosphere takes about 30 days to descend to the upper troposphere, where a condensation of waterdrops is produced which ultimately reach the Earth as rain. Through this condensation a depletion of water vapour in the upper atmosphere is occasioned, decreasing the "greenhouse" effect on the radiation balance.

It has even been surmised that an abnormal increase in the incidence of meteors may give rise, by a trigger action, to a deterioration of climate and possibly release a glacial epoch.

No wonder that students of the atmosphere and its radiation balance are taking a growing interest in meteoric dust.

THE ANNUAL ACCRUEMENT OF COSMIC SPHERULES

In trying to work out the total weight of the cosmic spherules settling on to the surface of our planet the numbers of spherules found in the cores investigated can be used, converting the numbers of spherules per kg. into weights. But already this conversion from numbers into weights implies an element of uncertainty.

We have counted all spherules of a diameter exceeding 30 μ and then computed the total number accruing to the Earth for one year. These values are set out in column 7 of Table 3. In converting numbers into weights we have assumed a specific weight of 5.0 and a diameter of 40 μ, assuming that all the spherules belong to the size-class 30–60 μ. When taking the total counted number instead of the number of the size-class 30–60 μ, we add about 10 per cent as a correction for the weight of the spherules of a diameter less than 30 μ. In this way the values set out in column 8 have been obtained. Finally, column 9 shows values of the total accruement of black spherules of all sizes, the value being three times higher than those in column 8. The factor 3 we obtain by considering that the number of spherules between 30 and 60 μ is 8 times higher than the number of spherules exceeding 60 μ in diameter. (See Table 2.) The weight of the spherules of 30–60 μ is assumed to be equal to the weight of the fraction 60–125 μ and 125–250 μ.

TABLE 2

CORE NO.	TOTAL NUMBERS OF SPHERULES COUNTED		NUMBERS 30–60 μ / NUMBERS 60 μ
	30–60 μ	> 60 μ	
71	349	69	5
90	2,634	303	9
92	115	23	5
133	326	29	11
187	507	58	9
	3,931	482	8

Another still greater uncertainty enters into the calculation owing to the imperfectly known rate of sedimentation. Here one has to use approximate values involving possible errors by the factor of 2 to 5, in some cases even more.

The following values worked out at the present stage of our investigation must be given, therefore, with due reservation. Compared to earlier figures given by other investigators our estimates are very moderate but are necessarily subject to an revision when more extensive investigations now pending have been carried out.

In general one gains the impression from these tables that the meteor frequency has been considerably above the average in recent times, as is also indicated in most of the frequency diagrams. However, we must emphasize the great difficulties inherent in the method of sampling. First, the surface layer may be missing, a layer which may quite well represent a sedimentation time of tens of thousands of years. Further, owing to different rates of sedimentation, a whole core like No. 187 probably represents a sedimentation time of less than 100,000 years, which corresponds only to a couple of cm. in Core 71. Hence, it is desirable to investigate a series of cores from different localities in order to arrive at really dependable values for the accruement of spherules and by this means to interrelate the results obtained from different cores.

Apart from the results given in the diagrams and in Table 3 we also have values from four other samples, two from the upper layers of two western Mediterranean (Cores 17 and 18), and two from the western Pacific Ocean (Cores 87 and 89). From Cores 17 and 18 the number of spherules per kg. lime- and salt-free sediment is 260 and 150 respectively. Assuming that the frequency of spherules is inversely proportional to the rate of sedimentation at a certain time we can, by comparison with Core 187 from the eastern Mediterranean, form an estimate of the rate of sedimentation in the western Mediterranean. We thus find a sedimentation rate of about 80 mm. in 1,000 years for Core 17 and a rate of 130 mm. in 1,000 years for Core 18, which are both quite reasonable figures. For Cores 87 and 89 the numbers of spherules were 1,725 and 1,165 respectively, and through a comparison with Cores 90 and 90 B we obtain a sedimentation rate of 6 and 8 mm. respectively in 1,000 years. These figures are three to four times higher than those found by Kröll (1955) from radium measurements. However, we do not know how far the uppermost samples in different cores represent the same span of time.

SUMMARY

The present paper gives the results from a study of the number of "cosmic spherules" present in sediment cores obtained from great depths in different parts of the ocean.

TABLE 3

Core No.	Depth in cm.	Rate of sedimentation mm/1000 y	$CaCO_3$ per cent	Span of time in years	Number of diam. > 30 per kg.	ANNUAL ACCRUEMENT OF BLACK SPHERULES: Number (> 30 μ) (10^{15})	Weight in tons (< 60 μ)	Total weight in tons
187	0–39	100	35	0?– 3,700	190	4.7	790	2,400
90	0–6.5	3	1	0?–20,000	3,350	1.6	265	800
90 B	4–12	6	56	7,000–20,000	3,350	1.6	270	800
92	64–81*	50	76	13,000–16,000	220	1.1	190	600
133	3–18	10	15	3,000–18,000	700	1.0	160	500
71	0–26	1.5	1	0?–200,000	1,400	0.31	60	175
72	0–300	—	—	—	—	—	—	125†

* Section 0-64 cm. lost in transport.
† According to Laevastu and Mellis.

The number of such spherules obtained by means of a powerful electromagnetic extractor is tens of times greater than the numbers found by Sir John Murray and A. F. Renard by more primitive means.

Spherules in considerable numbers are found also in depths of several metres below the sediment surface, i.e., in sediments already deposited in Tertiary Time. This definitely refutes the hypothesis that meteoritic falls, from which the spherules are assumed to be derived, have been limited to a relatively recent past, the last 25,000 years.

On the other hand there are strong indications that the frequency of such spherules deposited in recent times, say in the last few thousand years, has been higher than in a more remote past.

There are also indications of intermediate maxima which may correspond to a greater frequency of meteoritic falls during certain times covered by our material. A systematic correlation of such maxima *inter se* has not been made.

Comparing the frequency of spherules found in recent times, i.e., near the surface, in certain cores affords means of estimating the approximate rates of sedimentation.

Converting the number of spherules found per kg. of sediment into weights makes it possible to estimate the total accruement of spherules to the whole Earth, the results being a moderate figure of 2,400 metric tons annually (with a possible rise to 5,000 tons), i.e., only a small fraction of figures obtained by earlier investigators from the number of magnetic spherules collected from the atmosphere. Means of obtaining more reliable figures for such spherules by establishing collection stations on mid-ocean islands are indicated.

In cases where the number of spherules from deep-sea cores have been analysed for iron, nickel, and cobalt, the presence of nickel has given a definite proof of the cosmic origin of the deep-sea spherules.

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Lord Howe Island, a Riddle of the Pacific

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THE RIDDLE of the origin and natural history of Lord Howe Island is not yet solved and the progress of our knowledge only shows us that the problem is more complicated than we can suppose. The fact is that the island, being only 7 miles long and half a mile in width, has quite a strange flora and fauna. They are not an accidental mixture of introduced species or of very widely spread elements, but consist of a number of endemic forms of which the relationships are not quite clear. Not only the presence of some families and genera is interesting but also the absence of others.

Lord Howe Island is situated only 300 miles from Port Macquarie and 420 miles from Sydney (Fig. 1), but the basic flora is quite different from that of the mainland of Australia. Neither eucalypts nor acacias are represented in its flora, nor parrots or magpies in its fauna. Norfolk Island is also not very far from Lord Howe Island (about 450 miles), but the araucarias, so typical of Norfolk Island, are quite absent on Lord Howe Island, although there are some beautiful specimens growing near homes as introduced trees. The typical elements of New Zealand are also practically absent on Lord Howe Island. The flora and fauna of Lord Howe Island are very specific, but where did their elements come from, if they are different from the countries westward, northward, and southward of Lord Howe Island?

Our knowledge of the flora and fauna of Lord Howe Island is very poor. We have not enough material for generalisation, although some interesting facts are known. Therefore, it will be wise to approach the problem only little by little by describing and analysing different groups of animals or plants. It will be useful to concentrate our attention on the problem not only in its details, but also as a whole. It seems to be that nobody yet has been especially concerned with this problem, but for the history of the Pacific it is doubtless of very great importance. In order to understand the fauna and flora it is necessary always to have in mind the following facts:

1. On Lord Howe Island are growing four different species of palms, all endemic (Figs. 2, 4). That gives us a reason to think that the flora of the island is basically a tropical one. We cannot expect the development of four species of palms in quite recent time, so that it is quite evident that a mild climate has existed on the island for a very long time, and the fauna also must have developed the elements characteristic of a subtropical or tropical origin.

2. There are two mountains on the island (2,500 ft. and 2,800 ft.) which can give a place for development of the elements of a flora and fauna typical of a more temperate climate. (See Fig. 3.)

3. Apart from bats, mammals are absent from the island, nor are there fossils evident. There are only rats and mice, introduced by man. The rats have played an extremely important part in the impoverishment of the fauna. They caused the extinction of not only

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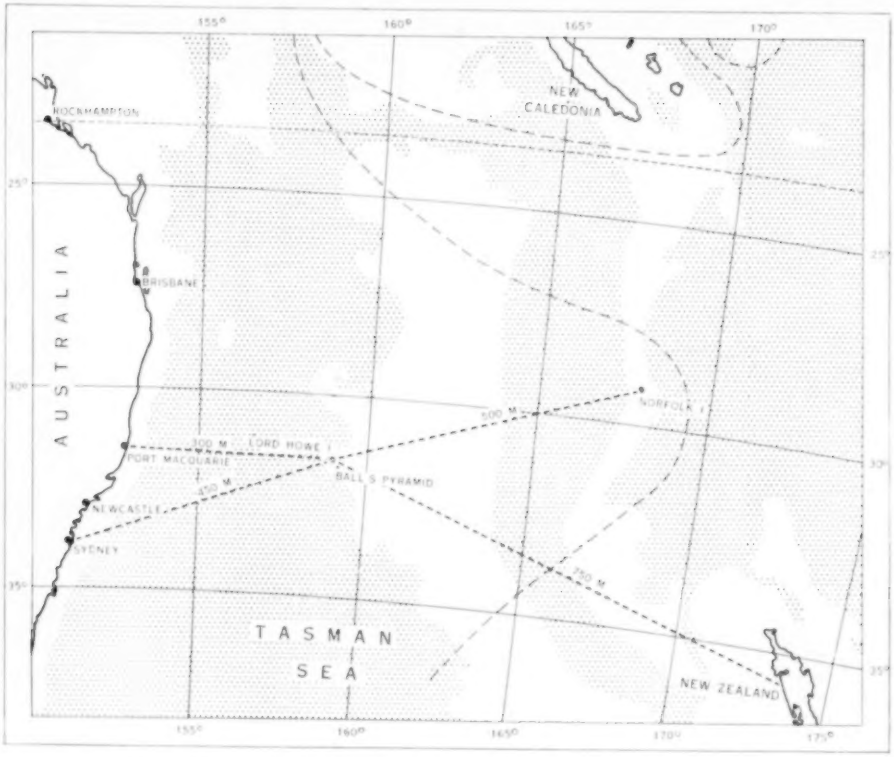

FIG. 1. Map showing position of Lord Howe Island. Latitude, 30° 33′ S., Longitude, 150° 5′ E.

some endemic birds but also of one species on insect, *Carabidion australe*, a phasmid.

4. The endemism of some elements of fauna, for example, of birds is very great, not only among the existing species but also in those recently extinct, some of which were completely restricted to the island.

5. Characteristic also is the absence of some Reptilia: snakes are quite absent, fresh water Chelonias also. There are recorded only three species of lizards. Amphibia are quite absent. An extinct turtle (probably a sea species)—*Meiolania platyceps*—was not rare on Lord Howe Island. Of the other three species of this genus, one, *M. oweni*, was found at Darling Downs, Queensland; a second, *M. mackayi*, was found on the small Walpole Island (about 100 miles south east of New Caledonia); and the third, *M. argentina*, in Patagonia. *Meiolania platyceps* became extinct rather recently. (Anderson, 1925, 1926.)

6. There are data that various species of plants and animals arrived from time to time on the island, but later disappeared as a result of unfavourable conditions on the island, or from accidental causes, because the island is comparatively very small and the number of new immigrants usually is not so high as to resist occasional destruction.

7. The endemism on Lord Howe Island can be of two kinds: neoendemism and paleoendemism. The neoendemism can be very new, i.e., the species can be created in comparatively very short time: a flock of migrant birds can reach the island and produce a population with more narrow limits of char-

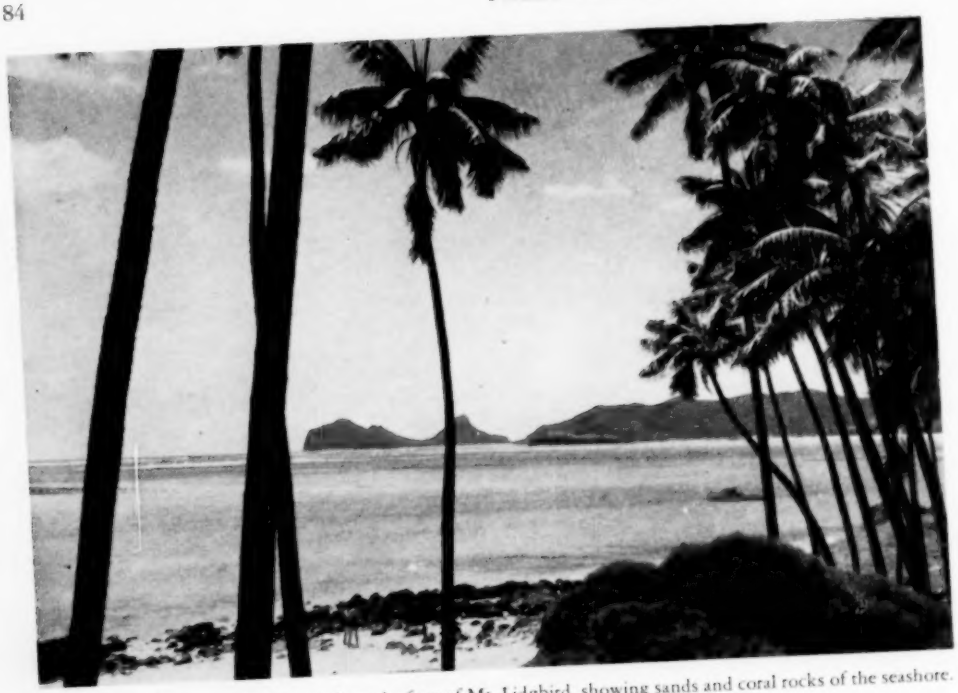

FIG. 2. A view across the lagoon, from the foot of Mt. Lidgbird, showing sands and coral rocks of the seashore. On the horizon is Mt. Eliza with its toothlike form. Photo by Miss Z. Liepa.

acters than the ancestral one. In a series of generations, which may be very small, a new species can evolve, distinct from the ancestral form but practically the same, being only impoverished in its genes (characters). This sort of endemism is of no interest to us. Only paleoendemism can give us solid data about the past of the island and its natural history.

8. Paleontological data about Lord Howe Island are very scarce because, first of all, no one has concerned himself with this matter, and second, the soils are not favourable for the preservation of fossils. The soils of the island are of two sorts: old coral reefs, which cannot contain the land fauna or contain only their occasional remnants; and volcanic soils or derivatives of them. The latter are situated very high on the island and are practically unexplored. It is possible that some bones of extinct birds, etc., could have been preserved by volcanic soils as result of a fall of rock, but nobody has been interested in their discovery.

9. The absence of some groups, families, etc., is a very complicated problem. First, it could be only lack of material, because nobody has systematically collected during a whole year on the island. Second, these groups may have been present but now are extinct owing to the influence of different conditions: the influence of man and his domesticated or semidomesticated animals, the introduction of stronger rivals, or a change of climate, all of which would have the stronger effect. Also their rarity could be caused by some too small biological niches on the island, etc. In this regard it is interesting to record the absence of such common fly families as Tabanidae, Nemestrinidae, Apioceridae, subfamily Asilinae, Coelopidae, etc.

10. Some Calliphoridae (Diptera) show

FIG. 3. A general view of Lord Howe Island from Malabar Hill. In centre, Mt. Lidgbird, at right Mt. Gower. The latter is 2,800 feet high. Photo by Miss Z. Liepa.

very interesting features in regard to their distribution: the *Calliphora hortona* group, with bright orange knobs at base of wings, so typical to New Zealand and present in Sydney area (probably introduced), are absent on the island.

Lucilia sericata Meig., a semidomesticated fly, is present in enormous numbers, but the Australian sheep blow-fly, *Lucilia cuprina* Wied., is quite absent. Very strange also is the absence of the typical forms of blow-flies of the mainland, *C. stygia* F. and *C. augur;* on Norfolk Island both species are represented, whilst on the mainland they are present literally everywhere.

11. There are some interesting caves at North Bay, but owing to the shattered condition of the rock, they are very dangerous to enter. One cave about three-quarters of a mile from the shore has been explored for about 250 yards. There are some fine stalactites and shawl formations in it, but the numerous cracks around show that there may be a great fall of rock at any time. These caves were not explored biologically, but the animals they shelter can give extremely interesting data about the origin of life on the island.

CLIMATE

In order to understand the origin and composition of the fauna of the island, it is necessary first of all to know the climate of Lord Howe Island.

Table 1 presents the data published by Russell (1895), based on eight years of meteorological observations relating only to the low parts of the island. The mountain area of the island is meteorologically unknown. It is

TABLE 1

COMPARISON OF THE CLIMATES OF SYDNEY, LORD HOWE ISLAND, AND PORT MACQUARIE

	SYDNEY	LORD HOWE ISLAND	ABOUT PORT MACQUARIE
	°F.	°F.	°F.
Mean shade temperature	62.9	68.6	65.3
Highest shade temp. ever recorded on any day	108.5	110.7	116.0
Lowest shade temp. ever recorded on any day	35.9	45.0	24.0
Spring mean shade temperature	62.9	68.0	65.6
Summer mean shade temperature	70.7	74.8	73.1
Autumn mean shade temperature	64.1	69.0	66.6
Winter mean shade temperature	54.0	62.4	55.7

AVERAGE MONTHLY TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Sydney	71.4	70.9	69.3	64.5	58.5	54.4	52.5	55.0	58.7	63.3	66.6	69.7	62.9
L. H. Is.	75.5	75.0	71.4	69.7	65.0	63.7	61.0	62.4	65.3	67.6	71.4	73.8	68.6
Port Macquarie District	74.0	73.4	71.9	67.3	60.5	56.1	54.3	56.5	60.8	65.9	69.6	72.0	65.3

evident that this area is much more humid and cooler. Clouds very often cover the tops of the mountains and rainfalls are more frequent there than on the low part of the island.

The comparison of the average monthly temperatures shows that the climate of Lord Howe Island is distinctly warmer than in Sydney (5.7°F. in year's temperature) and noticeably warmer than in Port Macquarie. The climate is more moderate, with only 14° of difference between the warmer and colder months, while in Sydney it is 19.9°, and in Port Macquarie 19.7°. This gives good ground for the existence of a number of tropical plants and animals, but it seems that the high humidity is a strong handicap for elements of the flora and fauna which prefer arid conditions.

It is necessary to add that the island is subject at times to strong winds and high seas. It is never very cold, as the warm current, which is also responsible for the most southerly coral reef in the world, helps to maintain an even climate which rarely goes below 60 or above 80 degrees Fahrenheit.

Annual rainfall is about 75 inches.

If we take meteorological data over the period from 1917 to 1938, the average annual rainfall was 67.30 inches. The mean daily temperature over the same period was 66.4 degrees, the mean daily maximum being 71.9 degrees and the mean daily minimum 60.9 degrees, with a difference only in 11 degrees. The highest reading recorded during that period was 89.0 degrees and the lowest 42.8 degrees.

Oliver (1917) gives the following tables on the climate of Lord Howe Island.

Atmospheric pressure varies regularly with the direction of the wind, being highest in south-east and east weather, and lowest in north-west and west weather. The highest reading recorded was 774.4 mm., on 9 June, 1912, east wind; the lowest, 750.3 mm., on 16 September, 1911, wind north-west.

Temperature, judged by both season and direction of wind, varies in a regular manner. The maximum temperature recorded was 30° C., on 8 February, 1912; the minimum, 6.1° C., on 30 August, 1911.

Rainfall is distributed fairly evenly throughout the year, though the average for the winter months is higher than that of the summer months. The average annual rainfall for 12 years is 1,818 mm., on 196 days. During the period selected for analysis, out of a total of 1,265 mm., 779 mm., or over 60 per cent, fell during northerly weather.

SOILS

The island consists practically of but two geological formations: a basaltic series forming about two-thirds of the island, and a thin-bedded calcareous deposit composed of coral sand, covering the lower ground and flanking the three isolated volcanic masses.

This coral-sand rock consists of comminuted and completely rounded coral debris, with grains of volcanic material such as augite, magnatite, and altered lava, with occasional fragments of echinoderms, shells, foraminifera, and other invertebrates. Generally speaking, the constituents of the coral-sand rock agree very closely with the component particles of the present beach at the island. It varies in thickness, and its greatest elevation is about 250 feet above sea level.

In such way the island is composed of two distinct types of rock, the older or base being of volcanic origin, and the upper of decomposed coral formed into a coarse sort of sandstone.

A noticeable feature of the coral rock is the stratification in layers; most of the layers are inclined at an angle of about 30 degrees. This lifting was thought to be caused by earth

FIG. 4. Inhabitated area of the island, "The Old Settlement." Large trees are araucarias, introduced from Norfolk Island. In mid-photo are the dominating Howea palms. A line of surf marks the boundary of the coral reef. Rabbit Island in background. Photo by Miss Z. Liepa.

TABLE 2
WEATHER DATA, BY MONTHS, LORD HOWE ISLAND

	BAROMETER	TEMPERATURE (C.°)			RAINFALL		RELATIVE HUMIDITY	CLOUD	WIND
	Mm.	Min.	Max.	Mean	Days	Mm.	Per Cent	0–10	Direction
1911									
July	762	13.1	17.9	15.5	21	192	79	6.4	S.W., S.E.
August	764	12.0	17.4	14.7	22	97	75	5.9	S.E.
September	762	13.6	20.2	16.9	8	154	75	7.1	S.W.
October	764	14.4	21.5	17.9	11	132	66	5.7	S.W.
November	762	16.8	23.8	20.3	8	91	73	5.6	N.W., S.W.
December	757	19.2	26.1	22.6	6	17	73	6.4	N.W.
1912									
January	760	18.8	25.5	22.2	10	83	65	6.2	S.E.
February	762	19.2	26.1	22.6	5	83	66	6.2	S.E.
March	761	18.3	25.3	21.8	14	73	62	7.0	S.E.
April	762	17.2	23.4	20.3	14	102	71	7.5	S.W.
May	764	14.1	20.5	17.3	20	113	71	6.4	S.E.
June	766	14.4	19.2	16.7	15	128	72	6.3	S.
Averages	762	15.9	22.2	19.1	154	1,265	71	6.4	

movements, but the theory now is held that the sand was deposited on the slanting sides of hummocks by the wind and hardened in successive layers when soaked with rain water.

The absence of shells in the coral rock is considered evidence that wind also played a part in carrying the sand into position, as shells, being heavier, were not carried as far as the sand.

There have been several uplifts on the whole island, and in one spot in particular the coral rock is seen about 400 feet above sea level. A portion of the west coast near the boat landing, seems to have sunk in recent times, as tree trunks and roots have been formed in position in the mud or sand, though now covered with 6 ft. or more of water at high tide.

The soil on the lower parts of the island is very rich in places, especially those parts which have been fertilized by decaying banyan trees, etc.

Most of the hill country is too rough and stony for cultivation, and the total area available for cultivation does not amount to more than 2,000 acres (Figs. 3, 4).

Before the advent of man on Lord Howe Island the only animals that had any effect on the plant formations and the soil were two species of burrowing petrels, *Puffinus carneipes* and *Pterodroma melanopus*. In talus slopes near the sea these birds make their burrows each year, completely overturning the soil and replenishing it with a rich manure; but whether or not this process is essential to bringing forth the edaphic conditions which result in the tussock sedge and herbaceous plant formations found there is difficult to say. These birds may have played a part also in the destruction of fossils.

VEGETATION

Oliver (1917) has made an analysis of the flora, and has stated that the whole flora contains 209 species of plants, among which 70, or 33 per cent, are endemic. In this number are not included 30 species of introduced plants and all cultivated plants.

Of the 169 genera of vascular plants 4 genera are endemic (*Colmeroia* and *Hedyscepe* are allied to New Zealand forms, *Negria* to

TABLE 3
THE DURATION AND CHARACTER OF WEATHER AT LORD HOWE ISLAND, CLASSED BY WIND-DIRECTION

	BAROMETER	TEMPERATURE (C.°)			RAINFALL		RELATIVE HUMIDITY	CLOUD	WIND
	Mm.	Min.	Max.	Mean	Days	Mm.	Per Cent	0–10	Days
South-east	764	15.3	21.9	18.6	23	44	67	6.0	71
East	765	16.2	22.6	19.4	12	75	70	6.6	28
North-east	764	15.7	22.5	19.1	17	136	71	5.8	39
North	761	18.0	23.2	20.6	20	317	77	8.2	30
North-west	760	18.6	24.2	21.4	21	326	77	7.4	46
West	760	14.3	22.5	18.4	13	165	77	7.3	22
South-west	761	15.0	21.8	18.4	34	157	69	5.7	80
South	762	15.2	21.7	18.5	14	45	70	5.7	50

both New Zealand and New Caledonian genera, while *Howea* is related to Malayan and tropical Australian genera).

Of the non-endemic genera 95 are widely distributed, occurring in Australia, New Zealand, and the rest of Polynesia exclusive of New Zealand; 47 more range widely throughout tropical countries, but do not reach New Zealand. Their presence may be due largely to the accident of latitude, and stamps the flora as subtropical. The remaining genera have the following range: New Zealand 1 (*Carmichaelia*), Australia 5, Polynesia 3, New Zealand and Australia 11, New Zealand and Polynesia 2, Africa 1 (*Moraea*).

Numerically, therefore, Australian genera (158) preponderate; Polynesia (exclusive of New Zealand) comes second with 147, and New Zealand has 109 genera. The presence of a large proportion of widely distributed genera and species might have been expected in the flora of an isolated island, because species possessing facilities for wide dispersal would naturally form the bulk of immigrants after land connection has been severed.

The author thinks that the presence on the island of the wedding lily, *Moraea Robinsoniana* Moore and Muell., is not a case of discontinuous distribution. It is more probable that it was transported by whalers, whose vessels very often landed on Lord Howe Island for fresh water. The whalers as a rule were visiting the cold waters of the southern hemisphere, and could easily transport unwittingly the seeds of this ornamental plant. This suggestion is not only theoretical: J. W. Maiden (1898) wrote: "The industry (of onions) commenced about fifty years ago through the finding on the beach (by Mrs. Andrew) of two or three onions which had been thrown overboard by a passing vessel." During stay in harbour the whalers' vessels usually did some cleaning and repair work, and all rubbish was thrown overboard.

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A Review of Australian Species of *Laphria* (Asilidae, Diptera), with Descriptions of Three New Species from Lord Howe Island

S. J. Paramonov[1]

KEY TO THE AUSTRALIAN SPECIES OF *Laphria*

1. Legs quite black, but can be covered partly by yellow hairs; if not very intense, always uniformly coloured 2

   Legs always partly yellow or orange . . 12

2. Wings marked with black and bright yellow or orange (Fig. 1). New South Wales . . . . . **L. ornatipennis** Macquart, ♂, ♀

   Wings hyaline or blackish, never with yellow markings 3

3. Hind margin of scutellum at most with four bristles, the central pair weaker and shorter than the lateral pair (Fig. 2*a*). 1 supraalar and 1 notopleural bristle. One black bristle at sides of tergites 1–5. Western Australia . . . . . **L. clavata** White, ♂, ♀

   Hind margin of scutellum with more than 4 bristles (Fig. 2*b*); if there are only 4 bristles, the middle pair is not shorter than the lateral one. Number of supraalar, notopleural and lateral bristles on abdomen not as above . . . . . 4[2]

4. Spots at sides of abdomen and hairs on the spots distinctly yellow; the lateral bristles are also yellow. Hairs and bristles very numerous and long. Queensland . . . . . **L. reginae**, sp. nov., ♂, ♀

   Spots at sides of abdomen pure white . . 5

5. Hairs on underside of head and on face reddish-yellow. Bristles at sides of abdomen numerous: on 1st tergite 4–5, on 2nd 3, on following 2. Lord Howe Island . . . . . **L. zentae**, sp. nov., ♂, ♀

   Hairs on underside of head and on face whitish. Bristles on sides of abdomen not so numerous; usually only one on each tergite 6

6. Wings quite black. Sides of mesonotum not silvery-marked. Disc of scutellum shining. Postscutellum with yellowish, not very noticeable dust 7

   Wings with black colour only along the veins. Disc of scutellum dusted. Postscutellum with strong silvery dust, similar dust on the sides of mesonotum . . 8

7. A very sharply marked cross furrow below the base of antennae (Fig. 4*a*). Proboscis longer than the height of head. Hairs on underside of hind tibiae whitish. Western Australia . . **L. leei**, sp. nov., ♀

   Only a slightly marked cross furrow below the base of antennae or furrow absent

[1] Division of Entomology, C. S. I. R. O., Canberra, Australia. Manuscript received May 4, 1957.

[2] *L. niveifacies* from Tasmania belongs to this group, but the description by Macquart is too short. Only after a study of all Tasmanian species of *Laphria* will it be possible to determine exactly this species of Macquart.

(Fig. 4*b*). Proboscis shorter than the height of head. Hairs on underside of hind tibiae black. Queensland, North Australia . . . . **L. maura,** sp. nov., ♂, ♀

8. Abdomen partly yellow. Western Australia . . . . . **L. lukinsi,** sp. nov., ♂, ♀

Abdomen wholly black 9

9. Prescutellar area (its declining part) covered with short bristles. Only one bristle on each segment of abdomen, at sides. New South Wales, Western Australia . . . . . **L. dayi,** sp. nov., ♂, ♀

Prescutellar area (its declining part) is quite bare, or the hairs are quite the same as the others on the mesonotum 10

10. Scutellum partly reddish, also the postalar calli. Queensland, Western Australia . . . . . **L. modesta,** sp. nov., ♂, ♀

Scutellum and postalar calli always black 11

11. Wings distinctly yellow at base. New South Wales . **L. campbelli,** sp. nov., ♂

Wings at base not yellow. New South Wales, Victoria . . . . . **L. mauroides,** sp. nov., ♂, ♀

12. Tibiae always partly yellow 13

Tibiae always wholly black 20

13. Ground colour of abdomen black, with the usual white or slightly yellowish spots at sides of 2nd–4th tergites 14

Ground colour of abdomen yellow, or with large yellow spots, or with narrow yellow lateral stripe, or at least with the last two tergites yellow 15

14. Length 12 mm. All femora yellow on their basal halves. White tomentose spots on the first four tergites. Thorax and scutellum dull black. Queensland . . . . . **L. fulvipes** Ricardo, ♀

Length 13.5 mm. or more. Anterior and middle femora with only yellow spots on basal halves. White spots only on 2nd, 3rd and 4th tergites. Mesonotum (if the insect is not greasy) with spots of golden dust on humeral calli and behind them, four golden markings at suture: two subcentral and two lateral; golden prescutellar area and golden disc of scutellum. Lord Howe Island . . . . . **L. pacifica,** sp. nov., ♂, ♀

15. Only the last two tergites are yellow or reddish. Abdomen with white spots at sides. Queensland . . . . . **L. bancrofti** Ricardo, ♀

The yellow or reddish colour occupies a greater area of the abdomen. Abdomen without white spots at sides 16

16. Only sides of tergites reddish, forming a narrow lateral stripe at sides of abdomen 17

More than lateral stripes are reddish or yellow 18

17. Tibiae with extremely long, bright yellow hairs. Fore femora nearly wholly black. "Australia" . . . . **L. hirta** Ricardo, ♂, ♀

Tibiae with extremely long black hairs. Fore femora with very large yellow spots on underside. Lord Howe Island . . . . . **L. howeana,** sp. nov., ♂, ♀

18. Borders of 2nd, 3rd and 4th tergites yellow. Length 11 mm. "Australia" . . . . . **L. calopogon** Bigot, ♂

Greater part of abdomen golden-yellow, the middle part can be camouflaged with black hairs. Length 12–13 mm. 19

19. Anterior and middle femora black. Queensland . . **L. burnsi,** sp. nov., ♂, ♀

Anterior and middle femora at base yellow (Fig. 6*d*). New South Wales, Queensland . . . . . **L. variana** White, ♂

20. Femora yellow. Abdomen without white lateral spots. Tasmania . . . . . **L. flavifemorata** Macquart, ♀

Femora predominantly black, partly yellow. Abdomen with lateral white spots 21

21. Legs black, only two-thirds of posterior femora yellow. Western Australia, Tasmania, New South Wales . . . . . **L. telecles** Walker, ♂, ♀

More parts of legs than two-thirds of hind femora are yellow 22

22. Anterior legs wholly black. Apical part of female abdomen depressed laterally (Fig. 3*a*). New South Wales, Victoria . . . . . **L. comata** White, ♂, ♀

Anterior femora at base at least with a yellow spot (Fig. 6*b*). Apical part of female abdomen rounded, not laterally depressed (Fig. 3*b*). Nearly whole of Australia . **L. rufifemorata** Macquart, ♂, ♀

Laphria zentae sp. nov., ♂, ♀

Belongs to the group with completely black legs.

Ground colour of body shining black. Head covered with a whitish dust, hairs and semi-bristles of face reddish-yellow; the central part of face (moustache) with black bristles. Some black bristles below base of antennae, on ocellar tubercle and on occiput, especially on the excavation of vertex. Hairs on antennae black. Third antennal joint elongated, elliptical. Proboscis short, only about half as long as the vertical diameter of head.

Sides of thorax, postscutellum and coxae with white dust. Mesonotum with reddish-yellow markings on humeral calli, two transversal spots of the same colour behind them, with a silvery marking at each side of suture, and similar marking near postalar calli. Scutellum with numerous black marginal bristles and with short yellowish and black hairs on the disc (Fig. 2*b*). In notopleural area (hind part) 3–4 long black bristles, 3–4 similar bristles in supraalar area, and 3–4 more on postalar calli. Prescutellar area nude.

Wings blackish in apical half and along hind margin, basal half nearly hyaline. Vein closing the discal cell (tp) straight. Cross vein r-m at end of basal third of the discal cell. First posterior cell at apex broad, slightly narrowed. Halteres yellowish.

Legs black, long and slender, hind femora only slightly swollen. Underside of anterior tibiae and metatarsi with very short but dense yellow hairs, in the form of brushes; lateral and dorsal sides with very long, black hairs and bristles; anterior femora with yellow and black hairs, the black ones only on upperside, but without strong bristles. Mid-legs very similar to the anterior, but without the yellow brushes and with some strong bristles on apical part of femora. Hind legs similar to the middle ones, metatarsi not swollen, maximally as broad as apex of tibiae and nearly as long as three following segments combined. Claws of all legs slightly yellow at base. Pulvilli yellowish.

Abdomen elongated, longer than in other species, black, shining, laterally with white spots on first to fourth tergites. Hairs on lateral side yellowish, not dense. At sides of first tergite 4 black bristles, on the second 2–3, on third, fourth and fifth 2 bristles. Genitalia rather large, black, shining, with black and whitish hairs.

Female differs only slightly from the male. Long yellowish hairs are paler, whitish, but on head reddish as in male; abdomen slightly broader.

Length of body 19 mm., of wing 15 mm.

1 ♂, 29.xi.1955 (type), 1 ♂, 5.xii.1955, Lord Howe Island, N. S. Wales (S. J. Paramonov and Z. Liepa); 1 ♂, 19.ii.1957, North Bay, Lord Howe Island (Z. Liepa); 1 ♀, 29.xi.1955, 1 ♀, 28.xi.1955, Lord Howe Island (S. J. Paramonov and Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

This species is not very closely related to the mainland species, but superficially looks very similar to *L. dayi* sp. nov.

Laphria pacifica sp. nov., ♂, ♀

From the group with yellow-marked tibiae.

Face and frons dusted with yellow; face with long, black bristles of moustache and below the antennae, and with central part covered with dense golden scalelike hairs. Underside of head with white hairs. Most of occiput, ocellar tubercle and antennae clothed with black hairs. Third antennal segment extremely elongated, narrow, broadening slightly towards the apex. Proboscis long, about as long as vertical diameter of head.

Mesonotum with golden markings on humeral calli; behind them on the sides of sutura, two small subcentral markings; golden markings also on prescutellar area and on the disc of scutellum. Propleurae and mesopleurae also golden but not so distinct as the mesonotum. Sides of thorax whitish and yellow dusted. Two notopleural bristles, 3–4 supraalar, 4 postalar. Prescutellar area quite nude. Scutellum with numerous long, black and white, marginal hair-bristles; disc with very short, yellowish ones.

Wings on apical two-thirds black, basal third hyaline. Veins closing the fourth posterior cell not straight but convex. Halteres yellow.

Legs black, but all femora and tibiae with reddish-yellow markings. All femora very swollen, the anterior only slightly yellow at base; the middle with basal third yellow; the hind with basal half yellow. Hairs on yellow parts of legs yellow, on remainder black. Bristles on femora practically absent. Tibiae with extremely long hair-bristles, especially the middle tibiae, and with yellow markings occupying their middle half. Hind tibiae distinctly curved. Pulvilli yellow.

Abdomen black, with slight blue sheen, and with 3 small white or slightly yellowish spots of dust on sides of second, third and fourth tergites. Hairs on sides yellowish, not very numerous. Genitalia very large, swollen.

Female very similar to the male. The abdomen comparatively broader, and the spots at sides of second to fourth tergites larger and whiter. Hind metatarsus distinctly swollen.

Length of body 14.4 mm., of wing 11 mm.

1 ♂, 18.xii.1955 (type), Lord Howe Island, N. S. Wales (S. J. Paramonov); 1 ♂, 1 ♀, 28.xi.1955, 1 ♀, 30.xi.1955, Lord Howe Island (S. J. Paramonov and Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria howeana sp. nov., ♂, ♀

Belongs to the group with yellow-marked tibiae, but without spots of white or yellow dust at sides of abdomen.

Very similar to *L. pacifica* sp. nov., but white spots at sides of abdomen replaced by a narrow reddish longitudinal stripe. This stripe is not visible from above but is clearly visible from the lateral view. Golden markings on mesonotum brighter, postscutellum silvery. The yellow colour on legs is brighter and more extensive: it occupies the basal half of anterior and middle femora and a slightly greater area of hind femora.

Length of body 18 mm., of wing 14 mm.

1 ♂, 29.xi.1955 (type), 7 ♂♂, 25.xi.–29.xi.1955, 11 ♀♀, 23.xi.–29.xi.1955, Lord Howe Island, N. S. Wales (S. J. Paramonov and Z. Liepa); 3 ♀♀, 20.xi.1956, Dawson Range, Lord Howe Island (Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Some specimens have nearly hyaline wings, although as a rule the apical two-thirds is dark.

It is quite evident that all three described species are common on the island, but other representatives of Asilidae are very rare. Only one species of Dasypogoninae was collected, but no Asilinae, Stichopogoninae or Lepto-

gastrinae were seen on the island by myself or by my assistant.

All three described species are rather closely related to the mainland species, but none of the mainland species were found on the island. The circumstance that all three species of the same genus are different from the mainland species seems to be a convincing sign of true paleoendemism.

The relationship between species from Lord Howe Island and those from the mainland are easily seen from the above given key to identification of all Australian species known to the author.

Laphria clavata White, ♂, ♀

Laphria clavata White, 1913. Roy. Soc. Tasmania, Proc. 1913: 273.

Laphria clavata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 357.

Laphria clavata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 519.

Type in the British Museum, London.

This species is recorded only from Western Australia. On the abdomen the small white lateral spots are present only on the 2nd, 3rd and 4th tergites, but not on the 1st. Claws and pulvilli in female about as long as in male. Wings distinctly smoky in their distal half. A rather common species (Fig. 2*a*).

Laphria ornatipennis Macquart, ♂, ♀

Laphria ornatipennis Macquart, 1849. Dipt. Exot., Sup. 4: 73.

Laphria ornatipennis Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 156.

Laphria ornatipennis Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 357.

Laphria ornatipennis Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 520.

Type in the Paris Museum.

The moustache in the male consists of soft, long golden hairs and bristles, in the female of stout black bristles and some yellow hairs. A bright yellow third antennal joint is characteristic of this species alone. Two bright yellow triangles in the fore part of the wing also separate this species at once from all other species (Fig. 1).

Distributed in Eastern states of Australia and not very common.

The author has seen specimens from the following localities: New South Wales: 1 ♂, 31.xii.1923, Broken Bay (Mackerras); 1 ♂, 1.i.1926, National Park (Mackerras); 1 ♂, 12.iii.1953, Colo Vale (R. Mykytowycz); 1 ♀, 12.i.1935, 1 ♀, 25.ii. 1935, Killara (M. F. Day); 1 ♀, 17.i. 1935, Port Macquarie (M. F. Day); 1 ♀, 2.xii. 1950, Nellingen (K. L. H. Key).

FIG. 1. Pattern of wing of *Laphria ornatipennis* Macq. (Shaded portion is brown, unshaded portion is yellow.)

Laphria fulvipes Ricardo, ♀

Laphria fulvipes Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 158.

Laphria fulvipes Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 359.

Laphria fulvipes Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 522.

Type in the British Museum, London.

Only the female is described. This species is unknown to the author.

FIG. 2. *a*, Scutellum of *Laphria clavata* White. *b*, Scutellum of *Laphria zentae* sp. nov.

Laphria bancrofti Ricardo, ♂, ♀

Laphria bancrofti Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 158.
Laphria bancrofti Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 359.
Laphria bancrofti Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 522.

Type (female) in the British Museum.

The considerable difference in the size of the sexes (♀—11 mm., ♂—17 mm.), the absence of spots on the sides of the male abdomen, and the difference in the colour of the femora show that the male probably does not belong to the same species as the female.

The author has seen only 2 specimens: 1 ♀, Palm Island, Queensland (Bancroft) and 1 ♀, 25.i.1949, Goodna, Queensland (I. F. B. Common), but he is not quite sure that the identification of the species is correct, both specimens have pure white, rather than yellow, markings on the mesonotum.

Laphria hirta Ricardo, ♂, ♀

Laphria hirta Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 159.
Laphria hirta Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 359.
Laphria hirta Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 522.

Type (male) in the British Museum.

The author has seen only one male specimen—1 ♂, 30.x.1950, Heathcote, New South Wales (T. R. Henry). This species is easily recognisable by the yellow spots laterally on each tergite, except the basal one. Hairs of face orange; on the frons and upper part of occiput black, on the lower part of occiput pure white. Moustache consists of about 12 long, fine, black bristles. Proboscis long, as long as the head is high, compressed laterally. All femora extremely swollen; all tibiae with extremely dense and long hairs, each of which is about three times as long as the diameter of the corresponding tibia. Hypopygium large, black, shining, rounded, as long as the last tergite. Sides of tergites with long, dense, orange hairs, directed downwards.

Female (hitherto unrecorded). 1 ♀, 14.xi. 1926, Woodford, New South Wales (Mackerras) is very similar to the male, but the hairs on the face are predominantly white, only slightly yellow at the sides, and all the femora swollen, though not to the same extent as in male.

Laphria telecles Walker, ♂, ♀

Laphria telecles Walker, 1849. List Dipt. Brit. Mus. 2: 376.
Laphria telecles Walker, 1855. List Dipt. Brit. Mus. 7, Sup. 3: 559.
Laphria telecles Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 154.
Laphria telecles White, 1916. Roy. Soc. Tasmania, Proc. 1916: 165.
Laphria telecles Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.

Types in the British Museum; from Western Australia.

The author has seen specimens from the following localities: 1 ♂, 5.xii.1936, Pemberton, Western Australia (K. R. Norris); 1 ♂, 25.xi.1914, Urella, New South Wales; 1 ♀, 13.ii.1948, Bendora, near Canberra, Australian Capital Territory (Paramonov); 1 ♀, 6.ii. 1923, Strahan, Tasmania (A. Tonnoir); 1 ♀, 30.i.1948, 13 mls. N. W. of Broadmarsh, Tasmania (Key, Carne and Kerr).

Laphria variana White, ♂, ♀

Laphria variana White, 1917. Roy. Soc. Tasmania, Proc. 1917: 72.
Laphria variana Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria variana Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 520.

Type (male) in the British Museum.

The remark of G. H. Hardy, ". . . the allotype female and a paratype are in Mr. J. Mann's collection," is based on a misunderstanding of the term "paratype." White described a "holotype" (single specimen) and it is quite evident that no paratypes existed. It

is also a very questionable practice to call a specimen of the second sex "allotype," without publishing an appropriate description.

The author has examined 1 ♂, 1924, Eidsvold, Queensland (Bancroft), and females from the following localities in Queensland: 2 ♀♀, Eidsvold; 1 ♀, 4.iv.1924, 1 ♀, ii.1923, Eidsvold; 1 ♀, 7.xi.1926, Lake Barrine (Goldfinch); 1 ♀, 1916, Tambourine; 1 ♀, x.–iv.1930, Eidsvold (T. L. Bancroft).

The female (hitherto unrecorded) is very similar to the male, but the central stripe of the abdomen is really black (in the male very often the black hairs only camouflage the yellow-red colour of the abdomen).

Both sexes of this species have anterior femora of a very peculiar colour pattern: on the underside and on the sides they are yellow, excepting for a small black apical area, but the upperside is black (Fig. 6*a*); in other species the dividing line of the areas of black and yellow colour is transverse to the long axis of the femur.

Laphria comata White, ♂, ♀

Laphria comata White, 1917. Roy. Soc. Tasmania, Proc. 1917: 85.
Laphria comata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria comata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type (male) in the British Museum.

The female was unknown up to the present; the note of G. H. Hardy, "the allotype female is in my own collection" cannot be accepted because this author has not published the description of the female.

The female is very similar to the male, but all femora are less strongly incrassate. From the females of other species it differs in having a very acute ovipositor, which, together with some of the apical abdominal segments, is strongly compressed laterally (Fig. 3*a*). This refutes the opinion of G. H. Hardy, 1934, that this form is only colour variety of *L. rufifemorata* Macq.

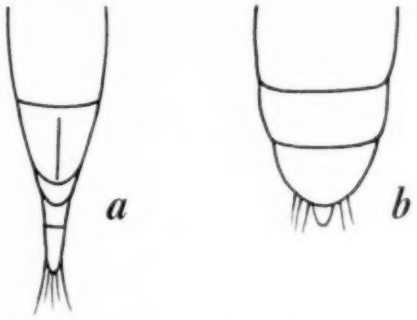

FIG. 3. *a*, Apical part of *Laphria comata* White, female. *b*, Apical part of *Laphria rufifemorata* Macq., female.

The author has examined the following specimens: Australian Capital Territory: 2 ♂♂, 17.ii.1953, Bendora, near Canberra (S. J. Paramonov); 7 ♀♀, 6.ii.1952, Lee's Springs, near Canberra (S. J. Paramonov); 1 ♀, 13.ii.1952, Mt. Gingera (S. J. Paramonov); 1 ♀, 15.iii.1948, 1 ♀, 31.iii.1948, Blundell's, near Canberra (S. J. Paramonov); 1 ♀, iii.1951, Westridge, Canberra (R. Richmond); 1 ♀, 15.iv.1953, Bendora (S. J. Paramonov); 1 ♀, 21.i.1931, Coree Creek, near Canberra (L. F. Graham). New South Wales: 1 ♂, 16.iv.1949, Chatswood (A. Dyce); 1 ♂, 11.i.1956, 7 ♀♀, 7.i.1956, Tubrabucca Ck., Barrington Tops, 4200 ft. (I. F. B. Common); 1 ♀, 9.iv.1949, Barrington Tops (S. J. Paramonov); 1 ♀, 28.ii.1936, Mt. Victoria (M. F. Day); 1 ♀, 25.xi.1914, Urella.

Laphria flavifemorata Macquart, ♀

Laphria flavifemorata Macquart, 1849. Dipt. Exot., Sup. 4: 73.
Laphria flavifemorata Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 157.
Laphria flavifemorata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria flavifemorata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type in the Paris Museum; from Tasmania.

This species is unknown to the author. There are no grounds for the remark of G.

H. Hardy, 1934, that "the type-locality of this species was probably Sydney, not Tasmania as recorded." G. H. Hardy, in various papers, expressed doubts about the validity of Macquart's recording many species as from Tasmania, as he had not found them there himself. However, in most cases I have examined, Macquart's data were quite correct.

In his paper G. H. Hardy (1929) also writes: "The leg coloration is variable, having a complete range as is found in the three forms mentioned above (*L. rufifemorata* Macq., *L. telecles* Walk., *L. comata* White), but is to be distinguished from them by the slender femora which conform to those species placed in group I (*L. tectamus* Walk., *L. clavatus* White, *L. ornatipennis* Macq.)."

G. H. Hardy, 1929, did not give the description of the male, nor the date and locality of collection of the specimens examined, and his expression, "the leg coloration is variable, having a complete range" is very obscure. It is probable that he was dealing with a mixture of species as he had also done with *Comptosia*, *Oncodes*, and other genera, when at least half a dozen species were confused together.

This species can be recognised easily by its yellow femora, concolorous abdomen devoid of lateral white spots, nonincrassate femora, and its venation.

Laphria rufifemorata Macquart, ♂, ♀

Laphria rufifemorata Macquart, 1844. Dipt. Exot., Sup. 1: 73.
Laphria rufifemorata Walker, 1855. List Dipt. Brit. Mus., Sup. 3: 559.
Laphria rufifemorata Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 154.
Laphria rufifemorata White, 1916. Roy. Soc. Tasmania, Proc. 1916: 166.
Laphria rufifemorata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 257.
Laphria rufifemorata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 520.

One of the commonest species in Australia, possibly distributed throughout the whole continent (Figs. 3*b*, 6*b*).

Type in the Paris Museum.

The author has examined specimens from the following localities: Australian Capital Territory: 3 ♂♂, 1 ♀, 15.iv.1953, Bendora (S. J. Paramonov); 1 ♂, 1 ♀, 28.iii.1951, Mt. Gingera (Common & Day); 1 ♂, 4 ♀♀, 6.iii.1952, Mt. Gingera (S. J. Paramonov); 1 ♂, 6.iii.1952, Mt. Gingera (H. M. Cane); 1 ♂, 23.i.1952, Lee's Springs (I. F. B. Common); 1 ♀, 15.iii.1950, Lee's Springs (S. J. Paramonov); 1 ♀, 14.i.1950, 1 ♀, 31.i.1952, Mt. Gingera (S. J. Paramonov); 1 ♀, 14.ii. 1953, Mt. Gingera (I. F. B. Common); 2 ♀♀, 2.iii.1949, 1 ♀, 31.i.1952, Bendora (S. J. Paramonov); 1 ♀, iii.1948, Brindabella; 1 ♀, 10.iv.1951, Brindabella (Small). New South Wales: 1 ♂, 12.xi.1953, Durras (S. J. Paramonov); 2 ♂♂, 8.i.1956, Upper Manning Riv., Barrington Tops, 4500 ft. (I. F. B. Common); 1 ♀, vii.1949, Kincumber; 1 ♀, 14.x.1952, 4 mls. N. of Bateman's Bay (S. J. Paramonov); 1 ♀, 12.xii.1951, 40 mls. N. of Sydney (E. F. Riek); 1 ♀, 22.xi.1925, Gordon (Harrison); 1 ♀, Acacia Plat. (J. Armstrong) Victoria: 1 ♀, 23.ii.1951, Mitta Mitta (B. Given). Tasmania: 2 ♂♂, 25.xii.1922, 1 ♀, 31.xii.1922, Advent Bay (A. Tonnoir); 2 ♀♀, 30.i.1949, Erriba (E. F. Riek); 1 ♀, 10.i.1932, Mt. Wellington, Ferntree (L. F. Graham); 1 ♀, 26.i.1948, near Wadamana (Key, Carne, and Kerr); 1 ♀, 11.ii.1949, Rose's Tier (R. A. Free).

Laphria calopogon Bigot, ♂

Laphria calopogon Bigot, 1876 (1878). Soc. Ent. de France, Ann. (5): 226.
Laphria calopogon Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 157.
Laphria calopogon Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria calopogon Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type presumably in the British Museum, London.

Since Bigot's time this species has not been recognised. Length of body 11 mm. Locality: "Australia." Type probably in Bigot's collection.

From the Latin and French descriptions we can extract the following characters: Black, sparsely greyish haired, some long hairs on the underside of abdomen and on the femora and tibiae; sides of face with golden hairs; beard white. Wings broadly black, almost hyaline at base. Halteres pale. Femora and tibiae at base narrowly yellow (or only the posterior tibiae have the yellow basal spots). Apical part of tibiae and underside of tarsi with golden-reddish pubescence. Pulvilli yellow. Margin of 2nd–4th tergite yellow.

Without examination of the type it is difficult to identify this species; close relationship to *L. variana* White is evident.

Laphria niveifacies Macquart

Laphria niveifacies Macquart, 1849. Dipt. Exot., Sup. 4: 73.
Laphria niveifacies Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 156.
Laphria niveifacies White, 1916. Roy. Soc. Tasmania, Proc. 1916: 167.
Laphria niveifacies Hardy, 1917. Roy. Soc. Tasmania, Proc. 1917: 66.
Laphria niveifacies Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria niveifacies Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

The type is apparently lost, as it could not be found in the Paris Museum.

Macquart's specimen was stated to be from Tasmania, but the species has not since been found there. Hardy, 1934, doubted the correctness of the locality record and supposed that the specimen came from Sydney, but my own experience has shown that Macquart's data about Tasmanian species were correct; Hardy's failure to find some species in Tasmania is not evidence that they are absent from Tasmania.

This species seems to be very closely related to *L. mauroides* sp. nov.

Laphria leei sp. nov., ♀

Belongs to the group of species with wholly black legs and wings, closely related to *L. maura* sp. nov.

Body black with a slightly bluish sheen, the usual greyish dust on head and underside of thorax almost completely lacking. Below bases of antennae, two-thirds up the height of the face there is a very distinct cross furrow, sharply separating the upper third (Fig. 4*a*). Sides of face with a narrow stripe of whitish hairs, bristles on the disc of the face (moustache) are long, black, but not very numerous.

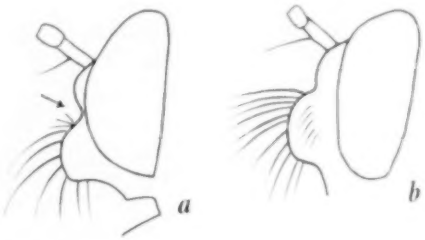

FIG. 4. *a*, Head of *Laphria leei* sp. nov. *b*, Head of *Laphria maura* sp. nov.

Proboscis long, black, shining, compressed laterally, slightly longer than height of head. Hairs on occiput whitish, except for some black ones above, which, however, are comparatively short and not as numerous as in other species.

Mesonotum dull, without grey markings, scutellum shining, with a row of sparse, comparatively weak, shortish marginal bristles. Disc of mesonotum without bristles. Pleurae dull, with some short whitish hairs. On the tubercle in front of halteres is a bunch of numerous, long, black bristles. Halteres yellow. Wings black, only alula and a part of axillar cell are nearly transparent. Fourth posterior cell with the closing vein, slightly convex and forming a very acute angle with m_3. Legs black, shining, with bluish or violet reflection. Pulvilli yellowish. Hairs very short, mostly whitish; bristles comparatively weak, short and not as numerous as in other species.

Hind femora swollen in apical half, but not long.

Abdomen comparatively short, shining, nearly bare; at sides of 2nd–4th tergites weakly developed whitish spots. Genital (last) segment very short. Lateral bristles only on 1st and 2nd tergites, but very weakly developed.

Length of body 16 mm., of wing 12 mm.

1 ♀, 17.i.1951, Wyndham, Kimberley Research Station, Western Australia (L. C. Lee).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria maura sp. nov., ♂, ♀

Belongs to the group of species with completely black legs and black wings, superficially similar to *L. lei*, but distinguishable easily by the absence of the cross furrow on the face below the antennae (Fig. 4*b*); by the shorter proboscis, which is shorter than the height of the head; by the presence of silvery spots on the mesonotum and other characters.

Ground colour of body black, shining. Face and occiput white dusted. Face at sides broadly covered by faintly yellowish hairs. Moustache consists of numerous, strong, black bristles. Hairs on underside of head slightly yellowish. Proboscis short, depressed from above. Frons whitish dusted, with light coloured short hairs and two very long black bristles on the ocellar tubercle. Antennae black, the third joint rather long, clavate.

Mesonotum with silvery or golden spots beside humeral calli and another pair of them slightly behind the calli; postalar calli usually golden or yellow dusted. Upper part of mesopleurae with a spot of silvery dust. Pleurae mostly without dust, with black hairs and a tuft of black bristles in front of the halteres which have a yellow knob. Wings rather uniformly black, comparatively broad and short. First posterior cell closed with a slightly concave vein far from the margin of wing.

Legs black, black haired and bristled, but the tibiae have an admixture of whitish hairs. Pulvilli yellow. Hind tibiae short, swollen.

Abdomen black, shining, with lateral whitish spots on tergites 2–4, nearly bare; only on the terminal segments are there more black hairs. Hypopygium of male swollen, but not very large; in female the last segment is short. On tergites 1–6 there are black bristles laterally.

Length of body 11–15 mm., of wing 9–11 mm. Queensland: 1 ♂, xii.1922, Eidsvold (type) and a female; 1 ♂, 19.i.1949, Yeppon (I. F. B. Common); 2 ♂♂, 1 ♀, 2.–3.iv.1929, Burnside (T. G. Campbell). The last 3 specimens with a closed first posterior cell.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria reginae sp. nov., ♂, ♀

Belongs to the group of species with black legs; easily distinguishable by the presence of yellow spots on the abdomen.

Ground colour of body black, slightly shining; legs (in old specimens) may be brown, but never bright yellow or reddish.

Face and underside of thorax with very dense grey dust. Bristles and hairs on the head black, except below, where they are whitish. Bristles and hairs on mesonotum black, but on underside of thorax in the area above the fore coxae the hairs are whitish, and the very long bristles on the tubercle in front of the halteres are reddish. Hairs on mesopleurae long and black. The hairs and bristles on mesonotum are very long and thin. On the anterior part of the mesonotum there are two lateral spots of golden dust (chiefly on the humeral calli and a little behind them). Wings slightly greyish. First posterior cell slightly narrowed at apex. Fourth posterior cell closed, much shorter than discal cell, its apical cross vein convex outwards, forming a very broad angle with m_3. Halteres yellow. In two specimens the second submarginal cell is divided by a supernumerous vein. The possibility is not excluded that these specimens might belong to a distinct species. Legs with very long hairs and bristles, mostly black.

Abdomen with rather bright yellow hairs. The lateral bristles on the first tergite are yellow, the long, strong bristles on the penultimate segment are black. On the sides of the 2nd–6th tergites there are small yellow, almost golden spots. Last genital segment is very short, directed downwards.

Length of body 12 mm., of wing 9 mm.

1 ♂ (type) Tambourine, Queensland, 1916 (Froggatt?); genitalia large, swollen, black, shining; two long lateral forceps on underside, and two very long lateral brushes of black, strong bristles. 1 ♀, Tambourine, Qld. (Davidson?); 1 ♀, 3.xi.1911, Mt. Tambourine, Qld.; 1 ♀, 1917, Mt. Tambourine, Qld.; 1 ♀, 1916, Tambourine, Qld., 1 ♀, 1926, Bulga, New South Wales (Froggatt); (the last two specimens with 3 submarginal cells).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria mauroides sp. nov., ♂, ♀

Belongs to the group of species with black legs and wings darkened along the veins, closely related to *L. dayi* sp. nov., but distinguishable by the presence, immediately over the scutellum, of short rather strong bristles, even on the declining part of mesonotum, by an irregular disposition of hairs on mesonotum (in *L. dayi* they are less numerous and distributed in longitudinal rows), and moustache tubercle not very sharply separated from the upper part of face.

Body black, shining. Head with greyish dust, very similar to that of *L. dayi* or *L. modesta*.

Mesonotum with similar markings as in *L. dayi*, but with short black hairs irregularly distributed. Wings dark, rather broad, the veins closing the discal and 4th posterior cells very close together and nearly parallel (Fig. 5*a*). Pleurae nearly entirely grey dusted, only the disc of the mesopleurae black, shining. Legs black, with hairs predominantly white. Femora moderately swollen. Halteres yellow.

Abdomen as in *L. dayi* sp. nov.

Length of body 15 mm., of wing 12.5 mm.

Australian Capital Territory: 1 ♂, 5.ii.1952, Lee's Springs (S. J. Paramonov), (type); 1 ♀, 2.ii.1954, Canberra (S. J. Paramonov); 1 ♀, 6.iv.1948, Blundell's (S. J. Paramonov). New South Wales: 1 ♀, 18.ii.1934, Killara (M. F. Day); 1 ♀, 10.ii.1955, near Queanbeyan (Z. Liepa). Victoria: 1 ♀, 10.ii.1954, Romsey (E. F. Riek).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria lukinsi sp. nov., ♂, ♀

Belongs to the group of species with black legs. Distinguishable at once by the yellow apical part of the abdomen.

Head black, with yellowish dust, hairs and bristles. The hairs at sides of face are flat and scalelike. Proboscis long, slightly shorter than head height, strongly compressed laterally. Palpi very small, hairs light coloured.

Mesonotum black, dull, with some yellow markings beside humeral calli. Short hairs black, but the longer ones in the prescutellar area yellowish. Bristles black, but those on postalar calli and scutellum yellow, very thin. Disc of scutellum with yellow depressed hairs. Underside of thorax yellowish dusted, with yellowish hairs and bristles. Only one black bristle on mesopleurae. Halteres yellow.

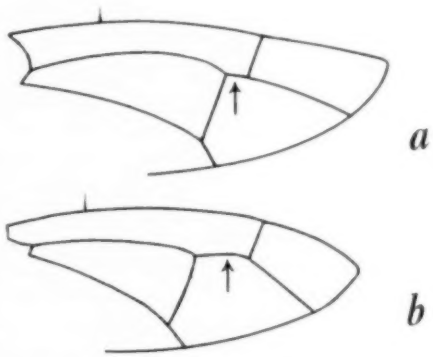

FIG. 5. *a*, Subdiscal cell of *Laphria mauroides* sp. nov. *b*, Subdiscal cell of *Laphria modesta* sp. nov.

Wings in apical two thirds strongly smoked but not black. First posterior cell at apex distinctly narrowed; 4th posterior cell closed close to hind margin of wing, only slightly shorter than discal cell. All veins black.

Legs black, pulvilli yellow, underside of fore tibiae so densely covered with short yellow hairs as to appear yellow. Hairs on tibiae extremely long, thin and yellow. All femora short and very swollen.

Abdomen narrow, cylindrical. First segment black, other segments becoming more reddish towards the apex. Lateral bristles yellow, weak. Discs of tergites with very short black hairs, along the hind margins there are numerous yellow hairs almost forming cross-bands. Hypopygium large, very swollen, reddish, with some separate bristles, but lacking tufts.

Length of body 14 mm., of wing 11 mm.

1 ♂, 5.xii.1953 (type), and 1 ♀, 11.xii. 1953, Wyndham, Kimberley Research Station, Western Australia (R. Lukins).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria modesta sp. nov., ♂, ♀

Belongs to the group of species with black legs and wings with saturated colour along the veins. Closely related to *L. mauroides* sp. nov., but easily distinguishable by its partly reddish scutellum and by the short subdiscal cell (Fig. 5*b*), which in *L. mauroides* is very slightly shorter than the discal cell.

Black, shining. Head with grey dust. Moustache tubercle sharply protuberant in profile (in *L. mauroides* not strongly separated from the upper part of face). Moustache consists of black bristles, hairs of face whitish. Proboscis short, depressed from above. Third antennal joint elliptical, elongated. Occiput with grey dust and whitish hairs, ocellar tubercle with 2 very strong, long, black bristles. There are some whitish spots on mesonotum beside the humeral calli, but they are poorly developed. Hairs on mesonotum predominantly whitish. Prescutellar area (declining part) with fine black and white hairs. Disc of scutellum and postalar calli reddish. Marginal bristles of scutellum very thin, hair-like, whitish; postnotum with strong white dust. Bunch of long hairs in front of halteres black. Halteres yellow. Wings rather strongly smoked, more so along the veins. First posterior cell distinctly narrowed at apex. Fourth posterior cell distinctly shorter than discal cell; the veins closing the discal and 4th posterior cell are not parallel; the lower angle of the latter is acute.

Legs black, mostly with white, shortish hairs; the fore tibiae lacking the usual extremely long bristles and hairs. Femora short, swollen. Tibiae dark brown.

Abdomen black, shining, with predominantly whitish short hairs laterally and white spots at sides of tergites 2–4. Hypopygium of moderate size. Lateral bristles mostly yellow; on apical segments they, as well as the hairs, are dark.

Length of body 9.5–13.5 mm., of wing 7–10 mm.

Females appear to be larger on the average than the males.

2 ♂♂, 3 ♀♀, 20.iv.1924, Eidsvold, Queensland (Bancroft), type male, labelled with a type label; 1 ♂, Jan.–Feb. 1923, Eidsvold, Queensland.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria dayi sp. nov., ♂, ♀

Belongs to the group with black legs, but with not absolutely black wings, easily distinguishable from *L. modesta* sp. nov. and *L. mauroides* sp. nov. by the presence of numerous, short bristles immediately above the scutellum, in the prescutellar area of the mesonotum.

Body black, shining. Head densely covered with a greyish dust, moustache area shining. Bristles of moustache very long, black, the lateral parts of the face covered with whitish

bristles and hairs. Moustache tubercle very well developed. Proboscis massive, short, acute, shining, black, depressed from above, not compressed laterally. On occiput about a dozen strong, black bristles.

Mesonotum shining, with some white spots on humeral calli, also beside them and at the sides of the mesonotum. Collare (pronotum) with a row of numerous black, short bristles. Pleurae also with whitish spots, but mesopleurae shining. Mesonotum bare, but there are three longitudinal rows of short, black hairs, and the prescutellar area is covered with numerous, long, erect hairs; area immediately above the scutellum with short black bristles. The tuft of long hairs in front of the halteres consists of black and whitish hairs. On margin of scutellum 8–10 long white hairs (reduced bristles). Wings dark, with colour saturated along the veins. First posterior cell rather broadly open. Fourth posterior cell very broad, slightly shorter than discal cell. Halteres yellow. Legs black, pulvilli brownish. Hairs on legs mostly whitish, the very long hairs usually present on tibiae are not very well developed in this species. All femora are very moderately swollen.

Postnotum strongly shining, almost silvery.

Abdomen strongly shining, nearly bare; on the sides of the tergites are some whitish hairs, and 1 black bristle laterally. On the sides of tergites 2–4 are whitish spots. Hypopygium of male not large, only slightly protruding.

Length of body 14.5–18 mm., of wing 10.5–15.5 mm.

New South Wales: 1 ♂, 14.ii.1928, National Park (Mackerras) (type), and 1 ♂, 1 ♀, same date and locality; 1 ♂, 20.ii. Gordon (D. F. Waterhouse); 1 ♂, 27.xii.1927, Dee-Why (M. Fuller); 1 ♂, 18.ii.1936, Killara (M. F. Day); 1 ♂, 3 ♀♀, 7.iv.1951, 17 mls. SSW of Bohena, Pilliga Scrub (Key & Chinnick). Western Australia: 1 ♂, 1 ♀, 30.xii. 1953, 12 mls. W. of York (J. H. Calaby).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria campbelli sp. nov., ♂

Belongs to the group of species with black legs; closely related to *L. mauroides* sp. nov., but having a distinct, bright yellow base to the wing.

Head as in *L. mauroides* sp. nov., third antennal joint also very broad, elliptical.

Mesonotum as in *L. mauroides* sp. nov., a pair of whitish spots beside the humeral calli, another pair at suture laterally, and a 3rd pair at the postalar calli. Hairs distributed irregularly on the mesonotum. A brush of thick short hairs on the underside at the apex of the hind tibiae is more strongly developed than in *L. mauroides*. First posterior cell is narrower at apex than in *L. mauroides:* only one-third of the width of the 2nd one, whereas in *L. mauroides* it is equal to one-half. Wings are distinctly narrower than in *L. mauroides*.

Abdomen as in *L. mauroides*.

Length of body 11–13 mm., of wing 8.5–9.5 mm.

1 ♂ (type), 12.iii.1957, Exp. area 3 mls. E. Pilot Hill, Bago Forest, Batlow, New South Wales. Phasmid Ecol. Exp. (T. G. Campbell); 1 ♂, same data and locality.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria burnsi sp. nov., ♂, ♀

Closely related to *L. hancrofti* Ric., but easily distinguishable by the reddish yellow abdomen in the male, and the reddish central half of the abdomen in the female.

Head as in *L. hancrofti* Ric., but moustache consists of distinct black bristles, not hairs. Facets near face are much larger than on the outside of the eye. Face occupying about one-fifth of head width. Palpi yellowish haired. Occiput predominantly yellowish haired, only on the upper part are there some long, black hairs.

Mesonotum as in *L. hancrofti* Ric., but bristles black in both sexes. Wings strongly darkened in their apical two-thirds, in the basal third almost hyaline. Hind femora very

swollen, especially in male.

Abdomen in male reddish, only the basal segment and genitalia deep black, shining. Hairs on 2nd and 6th tergites reddish, on 3rd–5th tergites black; these hairs are rather long and numerous, but depressed. Hypopygium very massive, rounded, and complicated in structure, longer than the 6th tergite. In the female the abdomen is black, but the central half is reddish, and covered with black hairs which camouflage the ground colour of the abdomen; last two tergites wholly reddish. The base of genital is also reddish but the remainder is black; hairs yellow.

This species is also very closely related to *L. variana* White, but its black anterior and middle femora permit it to be separated easily from that species, as the fore and mid femora of *L. variana* White are widely yellow in the basal part. The colour of the wing is also different from that of *L. variana;* the larger apical part is strongly separated from the hyaline base, whereas in *L. variana* the entire wing is uniformly coloured with an intermediate intensity.

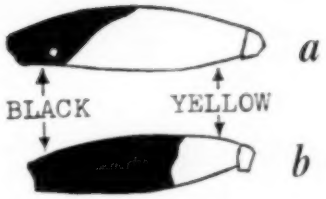

FIG. 6. *a*, Fore femora of *Laphria variana* White, female. *b*, Fore femora of *Laphria rufifemorata* Macq., female.

Length of body 13 mm., of wing 9 mm.

1 ♂ (type), 1 ♀, 11.xii.1949, probably in copula, Eubenangee, Nth. Queensland (A. Burns); 1 ♀, xi.1926, Meringa, Queensland (Goldfinch).

Type in the private collection of Mr. A. Burns, Melbourne.

Occurrence of *Protohydra leuckarti* in Puget Sound

WOLFGANG WIESER[1]

SINCE THE HYDROZOAN *Protohydra leuckarti* Greeff has always been considered an animal of great taxonomic and morphological interest, its discovery on the Pacific coast of North America deserves notice. This is the first record of the species for the Pacific Ocean. It was reported once before from the Pacific area, from a lake—probably a brackish one—in Kamtchatka (Abonyi, 1929).

My specimens are derived from two sand beaches on Puget Sound in the state of Washington, viz., from "Golden Gardens," within the city limits of Seattle on the east side of the Sound, and from Vashon Island farther south in the Sound. The species occurs in the lower intertidal zone of the beaches (from −1 to +3 feet), sometimes in considerable numbers. It was found in October 1955 and January 1956 at Golden Gardens, in May 1956 on Vashon Island. The sand is medium fine at the former locality, fine at the latter. A mechanical grain analysis of the two substrata gave the following results:

	Golden Gardens	Vashon Island
4760–2362μ	10.9%	0.1%
2362–1190μ	13.3	0.3
1190– 589μ	44.9	2.7
589– 295μ	26.8	19.1
295– 149μ	3.9	61.7
<149μ	...	16.1

The surface water of Puget Sound is of slightly reduced salinity; it varies from less than 27.5‰ in April and May to 30‰ in autumn months. This is true also for the central portion of Puget Sound. The water

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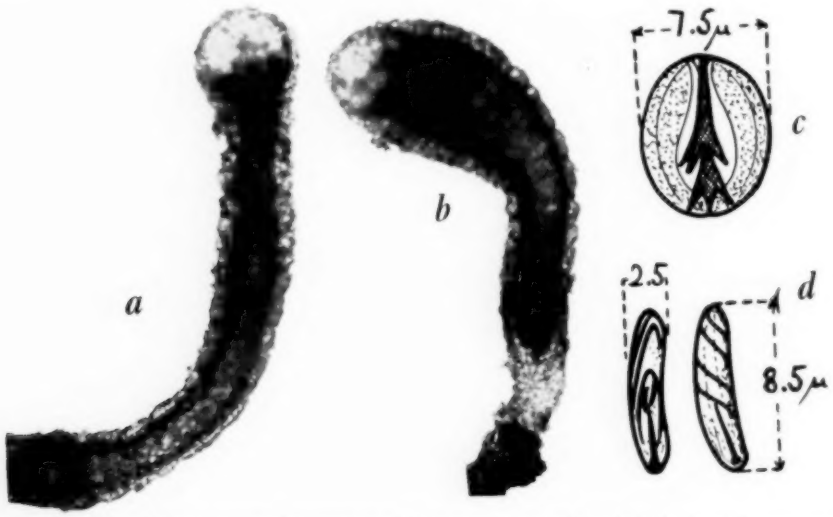

FIG. 1. *a* and *b*: Two different stages of contraction of the same specimen of *Protohydra leuckarti* (photomicrograph from life by Pat Dudley). Note the globular swelling at the anterior end in *a*. This is a typical stage after a wave of contraction has travelled through the animal from back to front. *c*: Stenotele (penetrant), *d*: isorhizas (glutinants), from an alcohol-fixed specimen.

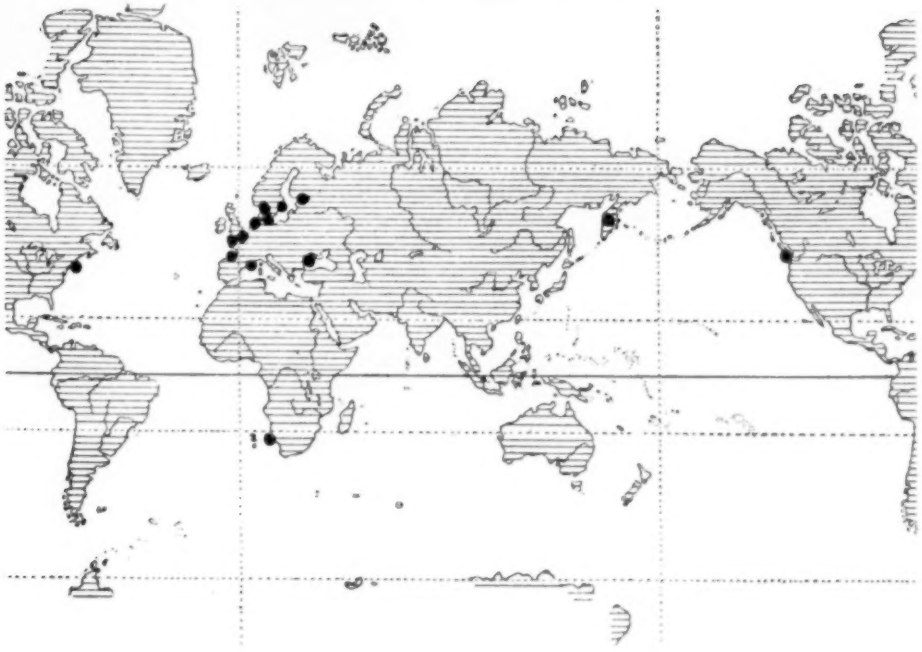

FIG. 2. Map of distribution of *Protohydra leuckarti*.

along the beaches is subject to greater variations in salinity due to the inflow of several rivers, but it never can be called brackish. Therefore, Ekman's statement (1953: 117) to the effect that *P. leuckarti* is a typical indicator of brackish water (that is, mesohaline, from 3 to 10‰) does not hold for this locality.

The temperature of the water is fairly stable the year round, varying from 8.5° in winter to 14° in summer. This, of course, applies to the central portion of the Sound only. The intertidal zone will be subject to greater extremes.

The fauna accompanying *P. leuckarti* is a typical sandfauna with gastrotrichs (*Turbanella* spp., *Macrodasys* sp., *Paraturbanella* sp.), cumaceans (*Cumella vulgaris*, *Lamprops krasheninikova*), many nematodes, etc. At Vashon Island, due to the finer substratum and the proximity of seaweeds, some representatives of a mud-fauna, e.g., *Corophium insidiosum* and *Leptochelia dubia*, occurred in the same habitat.

My specimens of *P. leuckarti* conform with previous descriptions. This is especially evident if the structure and size of the nematocysts, as shown in Figure 1*c*, *d*, are compared with the figures and data by Luther (1923), and Weill (1934).

In length the adult specimens varied between 0.7 and 2 mm., according to the state of contraction of the animal.

I have encountered copepods and nematodes in the body cavity of some of my specimens. Others were actually seen feeding on nematodes. In one case a *Protohydra* had begun to swallow a nematode about five times the length of the hydrozoan. By its violent movements the nematode had pierced the posterior end of its predator so that the latter appeared to be pulled like a sleeve over the prey. The body of the nematode was

covered with nematocysts that stuck to the cuticle.

Two species were sectioned, but there was no indication of gonads. Some specimens from Vashon Island, however, showed transverse fission. Although no zoogeographical conclusions can be drawn as yet, due to the absence of systematic studies in all parts of the world except the North European and, recently, the Mediterranean coast, I add a map (Fig. 2) with the distribution of *P. leuckarti* indicated. Recent information was contributed by Schulz (1950, 1952), Nyholm (1951), Valkanov (1947), Ruebush (1937), etc. The range of distribution makes it very likely that the species is cosmopolitan, as is already assumed by Nyholm.

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